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AN ASSESSMENT OF THE ENVIRONMENTAL EFFECTS OF DREDGED MATERIAL --ETC(U)

MAR 76 J J MAGNUSON, A M FORBES, R J HALL DACW37-74-C-0013

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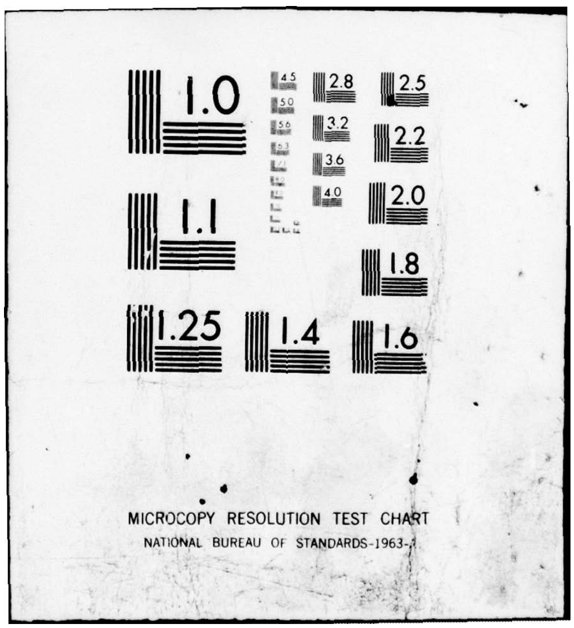
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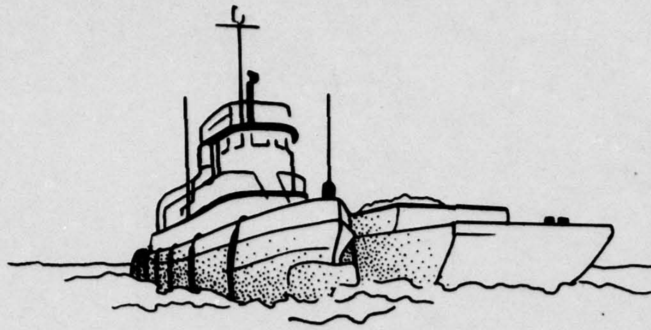

FINAL REPORT

AN ASSESSMENT OF THE ENVIRONMENTAL EFFECTS OF DREDGED MATERIAL DISPOSAL IN LAKE SUPERIOR

Volume 3

Biological Studies

By

John J. Magnuson, Ann Forbes, and Ronald Hall

MARINE STUDIES CENTER
UNIVERSITY OF WISCONSIN, MADISON

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OF

DREDGED MATERIAL DISPOSAL

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LAKE SUPERIOR.

A REPORT TO THE U.S. ARMY CORPS OF ENGINEERS
FROM THE MARINE STUDIES CENTER

Volume 3.

BIOLOGICAL STUDIES:

DULUTH-SUPERIOR AND KEWEENAW STUDY AREAS.

(12) 184p.

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AUTHORS AND CONTRIBUTORS

This study was conducted by Dr. John J. Magnuson, Professor of Zoology at the Laboratory of Limnology, University of Wisconsin-Madison. His co-workers at the Laboratory of Limnology were Anne M. Forbes, project specialist, and Ronald J. Hall, project associate. James L. Peterson, now at the Academy of Natural Sciences in Philadelphia, acted as project associate in the early months of the study. Short-term assistance was provided by many individuals. In particular, we are grateful to Walter Haag of the Trout Lake Biological Station of the University of Wisconsin, to student employees Frederic Funk, Rosemary Brothers, and Sandra Plisch, and to laboratory and field helpers Keith Nelson, Mark Jaber, William Albright, and Doug Stamm. The survey of shorebirds, gulls, and terns was done by Dr. Daniel E. Willard, associate scientist with the Institute for Environmental Studies, University of Wisconsin-Madison and undergraduate student Michael John Jaeger.

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A. Conclusions

1. Our literature review shows that Pontoporeia affinis is one of the dominant benthic animals in the Great Lakes and is an important food source for Lake Superior fish. Little is known about the ecology of Pontoporeia affinis in Lake Superior.

2. Our literature review indicates that the present knowledge of long-term ecological effects of dredging and dredged material disposal is limited and is based primarily on studies in marine environments. Little is known about the ecological effects of dredged material disposal in the Great Lakes.

3. Little is known about the effects of trace metals in sediments on benthic organisms. Our literature review indicates that most laboratory studies have investigated toxic levels of metals in the water column. Only one previous study was found concerning sublethal or lethal effects of harbor sediments on a Great Lakes organism, Pontoporeia affinis.

4. Pontoporeia affinis occurred in Lake Superior near Duluth-Superior in densities ranging from $0/m^2$ to $2628/m^2$ at depths of 2m to 140m. The average number of Pontoporeia with all collection dates and depths combined was $278/m^2$.

5. In controlled laboratory experiments, available mercury in sediments was taken up by Pontoporeia affinis and had an effect on their physical activity.

6. Controlled laboratory experiments demonstrated that available zinc in sediments was taken up by Pontoporeia affinis and had an effect on their physical activity.

7. Pontoporeia affinis developed whole body concentrations of mercury 100 to 1000 times their initial body burden of mercury during two-day, five-day, and two-week exposures to available mercury in sediments. Whole body concentrations of available zinc doubled during separate exposures of similar duration to zinc-enriched sediments.

8. Sublethal behavioral bioassays can be performed with fragile benthic animals like Pontoporeia affinis.

9. Sediment bioassays can be an important tool in determining the effects of polluted sediments on benthic animals.

10. Numbers of shorebirds (Scolopacidae and Charadriidae) were insufficient in the fall to allow an analysis of possible effects from spoil disposal.

11. Gulls (Laridae) were abundant in the fall and were located in areas heavily altered by man (i.e. breakwaters and garbage dumps).

B. Recommendation

Controlled laboratory experiments, designed to measure the effects of polluted sediments on benthic animals, should be refined and used to check additional pollutants including other contaminants covered by EPA guidelines for dredge spoil disposal.

ABSTRACT

Introduction

~~Our~~ This project was funded by the Corps of Engineers to study effects of in-lake dredge spoil disposal on toxicity and availability of heavy metals to the biota of Lake Superior. ~~We~~ Attention was focused on the benthic organisms in direct contact with the sediment. In the laboratory sublethal bioassays were used to examine effects of mercury and zinc contaminated sediments on the burrowing scud, Pontoporeia affinis. This amphipod is the predominant benthic invertebrate in Lake Superior and a major food base for Lake Superior fishes. ~~We: (1.)~~ Changes were observed ~~changes~~ in locomotor activity of Pontoporeia as a measure of their health on sediments with and without added mercury and zinc, and ~~(2.) measured~~ whole body concentrations of these metals were measured in Pontoporeia after exposure to the enriched sediments for periods of two days to two weeks.

The benthic communities near Duluth-Superior were surveyed and maps showing distribution and abundance of organisms were prepared. ~~We helped collect~~ samples were collected for background levels of various elements in sediments, invertebrates, and fish in Lake Superior. Shorebird populations were surveyed at Duluth-Superior and the Keweenaw Peninsula. ~~We~~ The authors also worked with scientists at Michigan Technological University to obtain similar information for the Corps of Engineers at the Keweenaw Waterway and adjacent Lake Superior.

ABSTRACT

I. Previous Work

A. The Ecology of Pontoporeia in the Great Lakes

1. Introduction

The biology and ecology of benthic organisms in the Great Lakes have been reviewed (Henson, 1966; Henson, et al., 1973; Cook and Johnson, 1974). The burrowing amphipod Pontoporeia affinis is the predominant member of macrobenthic community in all the Great Lakes and is a base to the food web leading to numerous economically important fishes. Pontoporeia are shown in Figure 39 on page 173.

Reported densities of Pontoporeia in the Laurentian Great Lakes vary from averages of $153/m^2$ in eastern Lake Superior (Adams and Kregear, 1969) to $14,000/m^2$ in the Straits of Mackinac (Henson, 1970). Other important benthos are oligochaetes, sphaeriids, chironomids, and the crustacean Mysis relecta. Details on distribution of benthic organisms in western Lake Superior are included in the discussion of our field study (Section II,D).

Pontoporeia affinis apparently invaded North America from the Eurasian coast and the Baltic Sea during the Pleistocene glaciation (Hensen et al., 1973). A series of glacial lakes and connecting waterways around the edges of the glaciers produced a continuous circumpolar body of water. As oceanic conditions changed, Pontoporeia migrated east through the continuous glacial lakes through the Bering Sea to North America. When the glaciers melted, Pontoporeia and a few associated organisms remained. These "glacial marine relict" organisms are found only in deep, cold oligotrophic lakes. Less than 50 such lakes occur in North America today, and all are found in the Great Lakes basin.

Henson (1970) points out that biological succession is being accelerated by man on a grand scale and that now is the time to act to conserve this unique and valuable fauna. Henson et al. (1973) consider Pontoporeia to be an endangered species.

2. Distribution of Pontoporeia in relation to depth, substrate and temperature

Maximum standing crops of Pontoporeia generally occur at intermediate depths (Henson, 1966). Eggleton (1936) and Cooper (1962) reported increasing densities as depth increased from 20 m to 50 m in Lake Michigan and from 10 m to 36 m in Lake Huron, respectively. Other studies have failed to confirm this correlation. In the Apostle Islands region of Lake Superior, maximum Pontoporeia densities occurred between 15 and 55 m (Selgeby, personal communication). In the Straits of Mackinac, Henson (1970) found that the range of maximum abundance of Pontoporeia occurred between 15 m and 45 m with a slight reduction between 25 m and 35 m. Marzolf (1965a) demonstrated no correlation between density of Pontoporeia and depths of 20 m to 120 m in Lake Michigan. Alley (1968) reported greatest abundance of Pontoporeia in Lake Michigan between 30 m and 60 m with the maximum at 30 m. In another Lake Michigan study, Powers and Alley (1967) found an average of 4000 Pontoporeia/m^2 at 10-20 m, 8,500/m^2 at 30 m, 6,000/m^2 at 50-60 m and 600/m^2 at 270 m.

Depth is only an index of a large series of environmental parameters involved in benthic distributions. Substrate relations of Pontoporeia in Lake Michigan were studied in field and laboratory experiments by Marzolf (1965a). Estimated organic content of sediment

was not correlated with numbers of Pontoporeia in the field. Positive relations between number of bacteria and Pontoporeia in the sediments and between number of bacteria and estimated organics were significant. In laboratory experiments Pontoporeia selected substrates to which organic matter had been added. Substrates with organic material as a surface layer were preferred over sediments with organics uniformly mixed. Henson (1970) and Henson et al. (1973) concluded that high densities of Pontoporeia occur where slope and current flow encourage the deposition of organic matter. This would explain the above mentioned dip in the numbers vs. depth distribution in the Straits of Mackinac since the reduction in numbers occurred where the slope was too steep for build up of organics. This is also consistent with preference for organic material shown in Marzolf's substrate selection experiments. The effect of dredged sediments on Pontoporeia was studied in substrate selection tests designed by Gannon and Beeton (1971). The amphipod selected open lake sediment over most harbor sediments.

A field study by Henson (1970) in the Straits of Mackinac related high densities of Pontoporeia with sediments low in clay (10-30%), high in sands (69-70%), and low in silt (10-20%). Pontoporeia were more abundant on sediments with a median particle diameter of 0.0625-0.125 mm. Sediment particle size and numbers of Pontoporeia in the field were not correlated in Marzolf's (1965a) studies; but in laboratory experiments, Pontoporeia selected sediment particle sizes 0.5 mm.

Pontoporeia is generally considered to be a coldwater stenotherm. The optimum temperature range was reported to be 8-12^{o}C by Henson

(1966).[1] However, Alley (1968) found high densities at 19°C. The upper tolerance limit was determined by Ekman (1915)[2] and Thienemann (1928)[2] as 14.5°C and by Segerstrale (1937)[3] as 14-20°C. Smith (1972) reported quite low median tolerance limits (TLm) in the laboratory: 12°C for 24 hours, 10.8°C for 96 hours, and 10.4°C for 30 days. Smith believed the low temperature tolerances were caused in part by agitation from sub-gravel filters in each of the tanks. The animals were transferred directly from a 6°C holding tank to the test temperatures of 9, 12, 14, 16, 18 and 20°C. Acclimation to 6°C was not mentioned as a possible factor in reducing TLm values below those expected from previous literature.

3. Reproduction and life history

Mature Pontoporeia range in length from 6 to 9 mm in Lake Michigan (Alley, 1968). When males become mature the length of the antennal flagella increases, and they begin to undergo open-water migrations (Alley, 1968). They apparently locate mature females with special sensory devices situated on the long antennae (Henson et al., 1973). Adult males have reduced mouth parts, do not feed, seldom live longer than a week after their last molt, and die soon after copulation (Segerstrale, 1950).[4] Fertilized eggs develop on the inner surfaces of the marsupial plates beneath the abdomen of females. The average

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1. Indirect reference from Gordeev, 1952; Segerstrale, 1959.
2. Indirect reference from Smith, 1972.
3. Indirect reference from Marzolf, 1965a.
4. Indirect reference from Henson et al., 1973.

number of eggs produced per female has been estimated at 20 (Juday and Birge, 1927). During incubation, the female's body begins to degenerate. The young are generally 2 mm long when released from the female, and she dies afterward.

In Lake Michigan brooding and spent females were present as early as March and as late as November in certain areas (Alley, 1968). Pontoporeia matured in one year at depths less than 10 m, two years at depths between 20 and 35 m and possibly three years at depths greater than 35 m. Beyond 35 m the amphipods have been reported to breed periodically during all seasons.

This pattern of reproduction and growth appears to be similar in the Great Slave Lake (Larkin, 1948)[1], Lake Huron (Cooper, 1962), and the Baltic Sea (Segerstrale, 1967).

Pontoporeia populations have different life cycle lengths in two basins differing in depth in South Bay, Lake Huron (Cooper, 1962). In the shallower 12 m basin, spring samples contained the young of the year and the one year old parent generation. This was indicative of a one-year life cycle. Spring samples in the 36 m basin yielded the young of the year, immature one year old juveniles and mature two year old parents. This indicated a two-year life cycle.

The upper temperature allowing successful reproduction has been measured at 7°C (Samter and Weltner, 1904; Larkin, 1948).[1] Smith (1972) observed successful laboratory reproduction in tanks at 6°C. Segerstrale (1967) rejected temperature as the synchronizing factor behind reproduction in the Baltic Sea because reproduction occurred simultaneously between 3 m and 35 m. Laboratory experiments indicated

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1. Indirect reference from Smith, 1972.

that decreased illumination in late summer induces gonad maturation so that reproduction occurs in the cold season. Embryonic development takes place in the brood pouch of the female during winter (Segerstrale, 1967). At depths below 100 m, Pontoporeia reproduced outside the cold season (Segerstrale, 1967).

4. Pontoporeia in the food web

Our interest in Pontoporeia and other Great Lakes benthic invertebrates is centered on food web relationships and the potential path of heavy metals through the benthic community. Marzolf (1965a) concluded that bacteria and/or organic matter in the sediment are the food sources utilized by Pontoporeia. This is based on the strong correlation between numbers of bacteria and numbers of Pontoporeia in sediments in the field and on the significant selection of substrates containing organics in the laboratory. Feeding by Pontoporeia was nonselective in the laboratory (Marzolf, 1965a). Materials were ingested indiscriminately from the substrate. The question remains as to what is assimilated. The critical experiments on energy transfer from substrate to amphipod remain to be done (Marzolf, 1965a).

Plankton obtained during vertical migration has been proposed as an alternative food source for Pontoporeia, but the planktonic portion of the Pontoporeia population at any one time was a small percentage of the total population (Marzolf, 1965b; Wells, 1968). The maximum occurrence in the plankton was 7.4% (Marzolf, 1965b). Marzolf (1965b) captured amphipods with the plankton only at night.

Wells (1968) collected Pontoporeia regularly in the day, although night tows caught more. Both researchers concluded that the function of vertical migration is not to feed on plankton. Marzolf (1965b) suggested that the migration is an adaptive behavior for the maintenance of genetic continuity between populations.

Predation by fishes on Pontoporeia has been well documented. Anderson and Smith (1971) completed a comprehensive survey of the food habits of 30 species of Lake Superior fish. Use of Pontoporeia as a food source by fish caught in trawls were, in decreasing order of importance: slimy sculpins, smelt, ninespine sticklebacks, trout-perch, fourhorn sculpins, lake trout, spoonhead sculpins, longnose suckers, bloaters, pygmy whitefish, lake whitefish, burbot, lake herring, shortjaw cisco, mottled sculpin, yellow perch and spottail shiner. The reader is referred to this document for detailed information.

Pontoporeia occurred in 97% of fourhorn sculpin (Myoxocephalus quadricornis) stomachs from Lake Superior and constituted 54% of the food volume (Jacoby, 1953). When sculpin stomachs in western Lake Superior contained Pontoporeia, the amphipod composed from 53-95% of the volume for slimy sculpin (Cottus cognatus), 42-100% for fourhorn sculpin, 98% for mottled sculpin (Cottus bairdi) (Anderson and Smith, 1971). Pontoporeia was the main food of all three sculpin species in the Apostle Islands region (Selgeby, personal communication). From July to September, fourhorn sculpin in the Baltic Sea migrate below the thermocline to feed almost exclusively on Pontoporeia (Westin, 1970). Westin believed that the distribution of Pontoporeia was controlling the distribution of the sculpin.

Pontoporeia contributed from 1-99% of stomach contents of longnose and white suckers in western Lake Superior (Anderson and Smith, 1971). Large burbot in Lake Superior feed seasonally on *Pontoporeia* (Bailey, 1972). In summer and fall, 73% of the food volume was *Pontoporeia* and *Mysis*; in winter 99.6% of the food volume was fish.

Pontoporeia is important in the food web supporting salmonid and coregonid fishes (Smith, 1972). The food of lake trout between 10.0 cm and 20.0 cm in length was 70% crustaceans (Dryer et al., 1965). Among the crustaceans, *Pontoporeia* was predominant when the trout were between 10.0 cm and 17.0 cm in length; *Mysis* was the most common food item for trout of 17.0 cm through 32.0 cm in length. The importance of crustaceans decreases for large trout. Several species of *Coregonus* (whitefish) have been reported to prey extensively on *Pontoporeia* (Pearse, 1921; Koelz, 1929; Larkin, 1929).[1] Pigmy whitefish feed on *Pontoporeia* in the Keweenaw Bay and Apostle Islands region (Eschmeyer and Bailey, 1954). Intensive feeding on *Pontoporeia* occurred in May and August. Little feeding on *Pontoporeia* occurred in October.

Fish preying on *Pontoporeia* then become prey to larger fish. Of 30 fish species sampled in western Lake Superior, four were fish-predators: lake trout, smelt, burbot and lake chubs (decreasing order of importance) (Anderson and Smith, 1971). The prey fish were typically smelt, sculpin, stickleback and trout-perch.

In Lake Michigan, lake trout and burbot consumed *Cottus cognatus* (Deason, 1939)[1] and *Cottus ricei* (Deason, 1939; Wright, 1968).[1]

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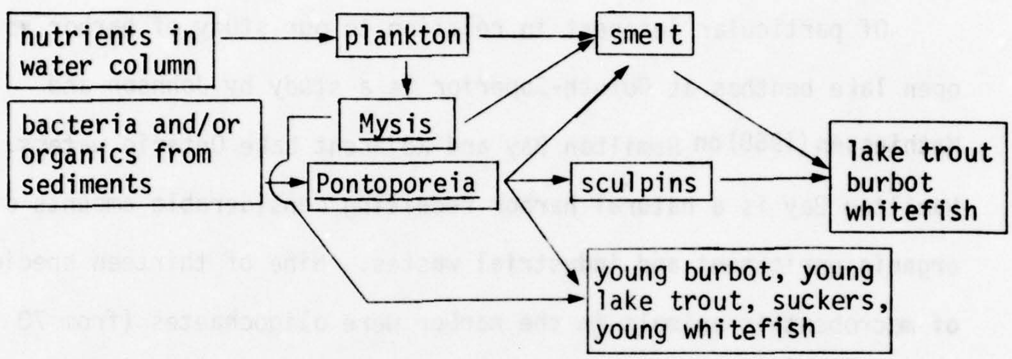
1. Indirect reference from Brandt and Magnuson, unpublished.

Cottus cognatus was the third most important fish to all but the smallest lake trout (Wells, 1973).[1] Myoxocephalus quadricornis was once heavily preyed upon by burbot and lake trout (Deason, 1939),[1] but now are rarely found in Lake Michigan trout (Wells, 1973).[1]

The simplified segment of the food web involving Pontoporeia in Lake Superior would be:



This predation process provides a potential concentrating mechanism for heavy metals from microcontaminants in sediments, through Pontoporeia, to sculpins and economically important fish species.

5. Oligochaetes and other macrobenthic fauna

While the ecology of Pontoporeia affinis is of central interest to our review, the ecology of its benthic co-habitants must be considered. These include oligochaetes, sphaeriids, chironomids, and the crustacean Mysis relecta. There are several recent reviews on benthic macroinvertebrates of the Great Lakes (Henson, 1966; Cook and Johnson, 1974).

Oligochaetes are important in the Great Lakes macrobenthos and have been reported as co-dominants to Pontoporeia (Henson, 1970).

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1. Indirect reference from Brandt and Magnuson, unpublished.

Their non-random distribution provides great variation between replicate samples and even greater variation at the same sampling site at different times (Brinkhurst, 1965). They become especially abundant in freshwater polluted with excess organic matter (Brinkhurst, 1965). Organic material in the sediments may be the factor controlling their distribution (Henson, 1962).

Of particular interest in relation to our study of harbor vs. open lake benthos at Duluth-Superior is a study by Johnson and Mathiessen (1968) on Hamilton Bay and adjacent Lake Ontario waters. Hamilton Bay is a natural harbor receiving considerable amounts of organic enrichment and industrial wastes. Nine of thirteen species of macrobenthic animals in the harbor were oligochaetes (from 70 to 22,600/m^2). Pontoporeia was absent. Six of 30 species were oligochaetes in the open lake (up to 1000 oligochaetes/m^2). Pontoporeia was most abundant in the open lake with a maximum density of 610/m^2.

B. Effects of Dredging and Dredged Material Disposal on Aquatic Organisms

1. Introduction

Most research interest in this area has been recent and concentrated on marine environments. Most investigations have been concerned with short-term problems relative to substrate disruption, acute toxicities, and gross changes in organism numbers and distributions. Nearly all investigators have stated that generalizations between study sites cannot be made. Each project must be evaluated individually with consideration for dredged material character and amount, for biological communities, and for the physical and chemical properties of affected substrates and overlaying water column. Little attention has been given to effects of dredged material disposal in the Great Lakes environment. A study of dredging and disposal activities at 37 Great Lakes harbors included some investigation of the effects of in-lake disposal on the lake ecosystems (U.S. Army Engineer Dist., Buffalo, 1969).

2. Effects of Dredging and Dredged Material Disposal

Short-term effects of dredging and disposal operations have been fairly well documented. An increase in turbidity is commonly observed; its effect reportedly ranging from undetectable to lethal for some fish and invertebrates (U.S. Fish and Wildlife Service, 1970). The sediment "blanket" formed over benthic environments in the disposal sites is reported as having immediate damaging effects on biota (Saila et al., 1971; Cronin, 1970).

Other more subtle effects of turbidity and new sediment build up include reduced photosynthesis, reduced feeding visability, disruption of spawning areas, reduced food supplies and vegetative cover, floculation

of algae, sorption of organic matter or inorganic ions and the trapping of organic matter with subsequent anaerobic conditions. These anaerobic conditions can, in turn, contribute directly to mortality of benthic fishes and invertebrates and may cause the release of other substances such as methane, sulfides and metals.

For the most part, studies have indicated that both dredging and subsequent disposal have caused decreases in both the total number of individuals and in species diversity (an index of the variety of species present). Cronin (1970) found that substantial increases in turbidity and nutrient levels did not grossly affect phytoplankton, zooplankton or fish in Chesapeake Bay. Due to a blanket of dredged material, however, numbers of benthic organisms were reduced by 70%. The return to original numbers of organisms occurred within 1.5 years. At the dredge site, the benthic populations returned to previous levels in one year, but the diversity of species was still reduced. Harrison (1970) found very rapid re-population rates in both dredge and disposal areas; organisms were introduced by active migration and by movement with currents.

Re-colonization of new substrates has been discussed by Carriker (1967) and Saila et al. (1971). Carriker claims that benthic tube dwelling forms are pioneers in colonizing new disposal sites in marine environments and that the tube dwellers modify the site's physical character. A succession of other colonizing organisms follows, with larval migration an important transport mechanism. If suitable substrate is not encountered, no resettlement will occur. Saila (1971) has enumerated factors related to settling and re-colonization.

They include surface texture, particle size, organic content, presence of other organisms, depth, and chemical and physical parameters of overlaying water. Re-establishment of some species of benthos and demersal fishes in San Francisco and San Pablo Bays after dredging occurred within a few months. Other species did not return to pre-investigation levels (U.S. Fish and Wildlife Service, 1970).

Physical alterations of an area by dredging may affect biological communities through such factors as changes in bottom geometry, modifications of bottom substrate and habitat, changes in water velocity and current patterns, modifications of the sediment-water interface with subsequent release of stimulatory (i.e., N and P) or toxic chemicals (i.e., heavy metals, pesticides), and creations of turbidity clouds (Boyd et al., 1972). In summarizing the ecological effects of dredging in coastal regions, Cronin et al. (1971) list the following: 1) removal of the sediment-water interface -- typically an area of high productivity, 2) removal of deeper substrates -- habitat for many burrowing forms, 3) creation of new deep water areas, 4) release of sediments and dissolved or absorbed chemicals into the water.

3. Freshwater Studies

A lengthy (twelve volume) summary of work on dredging and water quality in the Great Lakes was issued in 1969 by the Corps of Engineers (U.S. Army Engineer District, Buffalo, C.E., 1969). Boyd et al. (1972) review some conclusions of that report. Sampling and analysis procedures were not uniform and apparently did not allow for wide sediment variability. Dredging activities apparently had no effects in some harbors, temporary effects in others and beneficial effects in those where grossly

polluted sediments were removed. Studies of in-lake disposal were inconclusive as the fate of the dredge material after disposal was not clearly defined. Gannon and Beeton (1969) investigated specific effects of selected harbor sediments on plankton and benthos. They were able to construct five categories of harbor sediments relative to their effect on test organisms. These categories ranged from toxic (avoided by organisms and non-stimulatory to algae) to nontoxic (stimulating to growth of phytoplankton but not to benthic *Cladophora*). They suggested that chemical oxygen demand (COD), volatile solids, phosphate-phosphorus and ammonia correlate quite closely to their harbor categories and may be important parameters for supplementing biological data. Laboratory tests on *Pontoporeia affinis* showed definite selectivity of certain sediment types over others. In-lake sediments were clearly preferred over most harbor samples. Viability experiments indicated that sediments from "polluted" harbors were toxic to *Pontoporeia affinis* (Gannon and Beeton, 1971). The authors maintain that experimental procedures are an essential supplement to routine surveys. This idea is also supported by Flemer et al. (1968).

4. Heavy Metal Availability in Freshwater

Hutchinson and Fitchko (1974) stated that dredging and dredged material disposal in the Great Lakes may deteriorate the lake systems by putting heavy metals into solution and by suspending the fine particulate materials which have higher concentrations of heavy metals. Ritchie and Speakman (1973) discussed a technique which reduces heavy metal content before dredged material disposal. This was still in the experimental stages.

C. Trace Metals and Aquatic Organisms

1. Accumulation

Trace metals, entering the environment through sediments and the water column, may be incorporated into the living community. Once made available to the lowest trophic levels, they may be magnified (as is mercury) at successively higher levels (Gavis and Ferguson, 1972; D'Itri, 1972), or there may be little or no upward concentration in the food chain as is the case for arsenic (Ferguson and Gavis, 1972).

The relationships of trace elements in sediments and benthic organisms is of recent interest to researchers and little information exists about the subject. As benthic species composition changed in Anasco Bay, Puerto Rico, so did relative uptake of iron, zinc, scandium, and samarium (Phelps, 1967; Phelps et al., 1969). The concentration of these elements was more dependent on feeding behavior than on feeding location. The less dependent an organism was on sediment for its food source, the lower was its concentration of trace elements. Bottom-dwelling tubificids and clams reflected concentrations of metals (Cu, Ni, Pb, Cr, Li, Zn, Co, Cd) in bottom sediments of the Illinois River (Mathis and Cummings, 1973).

Background data on trace metals in Lake Superior fish exist (Lucas et al., 1970; Bails, 1972; Kleinert and Degurse, 1972; Kleinert, Degurse and Ruhland, 1974). Criteria for some trace metals in Lake Superior were recommended by the U.S. Department of the Interior (1969).

We will consider accumulation of zinc and mercury in detail; these are the two metals used in our study.

a. Zinc

Zinc is a trace metal essential to life processes, but it is highly toxic when excessive amounts are available to organisms. It is difficult to define what levels of zinc are necessary in living tissue and what levels are detrimental to organisms and ecosystems. There is little information in the literature on zinc in food chains. In two cases, one a polluted river (Table 1) and the other artificial ponds (Table 2), zinc is most concentrated in the sediments. Both sediments and organisms contain far more zinc than the water column. Zinc concentrations do not seem to magnify in organisms as do mercury concentrations.

Table 1

Illinois River, mean values for Zn (ppm), from Mathis and Cummings (1973)

Sediment	81	
Water	.031	
Clams	66-95	whole organisms
Tubificids	41	whole organisms
Carnivorous fishes	2.6-4.5	fillets only
Omnivorous fishes	3.3-10.2	fillets only

Table 2

Artificial ponds, concentration factors for Zn-65 over ambient water, from Hannerz (1968) in Eisler (1973)

Sediment	x20,000
Chironomid larvae	x1700
Snails	x590
Leeches	x400
Fish	highly variable (mean for pike is x1250)

b. Mercury

There is no known metabolic requirement for mercury in organisms, and it is toxic at very low levels. Organisms can concentrate excess mercury in their tissues - the level of this concentration depends on the type of organism and the form of mercury. Magnification of mercury in food chains leading to fish, aquatic birds, and man is well documented in the literature (D'Itri, 1972; Peakall and Lovett, 1972; Gavis and Ferguson, 1972). Concentration factors for various forms of mercury in organisms are presented in Table 3; inorganic mercury does not concentrate to the same extent that organically bound forms of mercury do. Other references for concentration of mercury in aquatic organisms are Johnels et al. (1967); Harriss (1973); MacLeod and Pessah (1973); Annett et al. (1972).

Aquatic organisms may potentially take up mercury through their food or directly from the water column. There is some controversy in the literature regarding the relative importance of these two routes of uptake. Is food or water more important? Mechanisms of mercury accumulation are not clear; there are probably a number of uptake patterns interacting in a complex way (D'Itri, 1972). Microorganisms interconvert the various inorganic and organic forms of mercury (Wood, 1974). Thus, they have a direct role in determining the form and availability of mercury in nature. The input of mercury into aquatic systems via industrial wastes has upset the natural cycling of small amounts of mercury in the environment.

Table 3

Concentration factors after a month following a single does of various mercury compounds into a pond (after Hannerz, 1968 in Peakall and Lovett, 1972).

	Mercuric Chloride	Methoxyethyl Hydroxide	Phenylmercuric Acetate	Methylmercuric Hydroxide
Water plants (six species) submerged parts[1]	4-264	68-771	40-2350	34-3200
emergent (three species)	3-77	4-53	8-90	8-25
Algae	252	920	1220	-
Moss	393	560	3900	5900
Invertebrates (four species)	247-560	510-1990	900-4200	3290-8470
Sediment	359	743	6800	6100

[1]Much of the variation is due to interspecific variation within the plants studied. For <u>Iris pseudacorus</u>, the values for the four compounds ranged from 4-98, while for <u>Lysimachia nummularia</u> the range was 264-3200.

2. Toxicity

Doudoroff and Katz (1953) and McKee and Wolf (1963) reviewed the toxicity of metals to aquatic organisms. Eisler (1973) prepared an annotated bibliography on biological effects of metals in aquatic environments. All of these studies involve metals in the water column rather than in the sediments. The recent trend in toxicity studies has been to carefully document water quality parameters (dissolved oxygen, pH, hardness, temperature, etc.) which alter heavy metal toxicities. Toxicities also vary with species and age of the organism. Recognition of these variables has facilitated the determination of permissible concentrations of pollutants and the explanation of the variability in toxicities reported in the literature.

Most studies concerned with biological effects of metals in aquatic environments have involved the determination of acute toxicities. What dosage of a metal will kill a certain percentage of the organisms in a specific period of time? This concentration is usually expressed as a TL_m[1] or median tolerance limit - the amount of metal to kill 50% of the organisms within the time period (usually 24, 48, or 96 hours). Of more recent interest and more environmental relevance is the sublethal experiment. What are the effects of long-term, non-acute levels of metals on organisms and subsequently, on their ecosystems? The use of sublethal measures of pollutant toxicity was reviewed by Sprague (1971). This type of

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[1]The notations TL_{50}, LC_{50}, and LD_{50} refer to the same calculation.

study involves measurement of parameters such as growth, reproductive success, metabolism, activity behavior, feeding behavior, and avoidance of water containing metals.

Birge and Just (1973, 1974, 1975) developed heavy metal bioassay procedures for developmental stages of birds, amphibians, and fish. The embryonic stage(s) in the life history of these organisms was most susceptible to heavy metals. Environmental standards must be set to insure survival of critical life stages.

Our study involved mercury and zinc in sediments. There is no information in the literature on the toxicity of sediment metals to aquatic organisms. The following review considers the available literature on the toxicity of mercury and zinc in the water column. Each metal is considered separately. In natural waters these metals will occur together and in combination with other metals, thus resulting in a combined or possibly synergistic effect. Cadmium concentrations, not normally toxic to the mummichog, Fundulus heteroclitus, reduce survival of the fish when mixed with copper and/or zinc (Eisler and Gardner, 1973). The toxic effects of mercuric salts are accentuated by trace amounts of copper (McKee and Wolf, 1963). Brown and Dalton (1970) reported on the toxicities of various mixtures of copper, phenol, zinc and nickel to rainbow trout. Extensive information exists on the effect of copper-zinc interactions on salmonid mortality and behavior (Sprague, Elson and Saunders, 1965; Saunders and Sprague, 1967). This review does not stress biochemical effects of toxic trace metals. Information regarding these effects can be found in such studies as: Christensen (1971-72) on effects of metal cations on blood enzyme activity in the white sucker, Catostomus commersoni; Jackim, Hamilin, and Sonis

(1970) on the effects of metals on liver enzyme activity in the killifish; and Hiltibran (1971) on metal effects on bluegill liver mitochondria metabolism.

a. Zinc

Skidmore (1964) has provided an extensive review of the zinc toxicity literature for aquatic animals. The toxicity of zinc compounds is modified by hardness, dissolved oxygen, and temperature; it depends on the species, age, and acclimatization of the individual. Chapman (1973) summarized the literature on zinc effects on the fathead minnow, Pimephales promelas (Table 4). Fathead minnow fry are more susceptible to zinc than are the eggs; the eggs are less resistant than are the adults. Adult fathead minnows in soft water are killed at a much lower concentration of zinc than they are in hard water.

Table 5 summarizes some of the recent zinc toxicity studies on invertebrates and fish. All of these involve toxicity of metals in water rather than in sediments, and most studies examine acute rather than sublethal toxicities. Zinc toxicity is increased by soft waters, higher temperatures, and reduced oxygen (Lloyd, 1960). Acute levels are more toxic to mayflies than to caddisflies and stoneflies (Warnick and Bell, 1969). Chronic exposure of zinc to Daphnia revealed a level permitting survival but impairing reproduction and weight gain (Biesinger and Christensen, 1972). Zinc and cadmium exerted an additive effect on freshwater shrimp at concentrations above one toxic unit (Thorp and Lake, 1974).

Zinc concentrations permitting prolonged survival still may be adverse to fish in terms of growth and reproduction (Crandall and Goodnight, 1962). Reproduction in fathead minnows was severely inhibited at zinc concentrations which had no effect on survival, growth and maturation (Brungs, 1969). Fathead minnows exposed to zinc as eggs and embryos develop a tolerance to the metal (Pickering and Vigor, 1965). The resistance of juvenile and adult zebra fish was slightly greater than alevins at high zinc concentrations and much greater at lower concentrations (Skidmore, 1965). The resistance of zebra fish was inversely proportional to the oxygen uptake at any one age (Skidmore, 1967). Low dissolved oxygen concentrations increased mortality of bluegills to zinc (Pickering, 1968). Zinc-65 tracer studies suggested that toxic effects on fish were caused by gill damage (Lloyd, 1960). Zinc caused epithelial damage to rainbow trout gills and decreased permeability of the gills to oxygen, resulting in tissue hypoxia (Skidmore, 1970). The ultrastructure of stickleback gills exposed to zinc was reported by Mathiessen and Brafield (1973).

There are few behavioral studies of zinc toxicity. In laboratory experiments, Salmo gairdnerii avoided sublethal concentrations of zinc in water (Sprague, 1968). The threshold avoidance level was 1/100 of the lethal level.

Table 4. Toxicity of zinc in water to the fathead minnow (Pimephales promelas). From Chapman (1973). Zinc values were converted to mg/liter (= ppm).

Stage	Zinc mg/liter	LC_{50} period	Temp. ^{o}C	Hardness mg/liter	pH	Source
Fry	.87	7 day	20	174-198	7.5	Pickering & Vigor (1965)
Adults	.88	96 hr	25	20	7.5	Pickering & Henderson (1966)
Eggs	1.6	12 day	20	174-198	7.5	Pickering & Vigor (1965)
Adults	7.5	96 hr	25	166	6.2	Rachlin & Perlmutter (1968)
Adults	9.2	96 hr	23[1]	200	7.7	Brungs (1969)
Adults	33.4	96 hr	25	360	8.2	Pickering & Henderson (1966)
50% Reduction in egg production	.088	10 months	20	200	7.7	Brungs (1969)

[1] Reported incorrectly in Chapman (1973). Revised according to Brungs (1969).

Table 5. Toxicity of zinc in water to aquatic organisms. Zinc values were converted to mg/liter (= ppm).

Organism	Reference	Toxicities and Comments
Protozoa		
Tetrahymene pyriformis	Carter & Cameron (1973)	96 hr TL_m = 5.77 mg/liter
Oligochaeta		
Tubificidae	Whitely (1968)	24 hr TL_m = 46 mg/liter
Crustacea		
Daphnia	Biesinger & Christensen (1972)	48 hr LC_{50} = .100 mg/liter without food, .280 mg/liter with food. Three-week LC_{50} = .158 mg/liter. Three-week 50% reproductive impairment = .102 mg/liter. Three-week 18% reproductive impairment = .070 mg/liter
Gammarus	Rewholdt et al. (1973)	24 hr TLm = 10.2 ppm; 96 hr TLm = 8.1 ppm
Paratya tasmaniensis (freshwater shrimp)	Thorp & Lake (1974)	96 hr LC_{50} = 1.21 mg/liter. Zn and Cd interacted < additively at concentrations less than one toxic unit. Above one toxic unit, interaction was strictly additive.
Insecta		
chironomid larvae	Podubsky & Stedronsky (1950)	fairly resistant to zinc
mayfly nymphs	"	zinc markedly toxic
Acroneuria lycorias (stonefly)	Warnick & Bell (1969)	50% survival at 14 days in 32 mg/liter

Table 5 (continued)

Organism	Reference	Toxicities and Comments
Ephemerella subvaria (mayfly)	Warnick & Bell (1969)	50% survival at 10 days in 16 mg/liter
Hydropsyche betteni (caddisfly)	"	50% survival at 14 days in 32 mg/liter
Pisces		
Salmo gairdneri (rainbow trout)	Lloyd (1960)	Decreased temperatures increased survival time but did not change threshold toxicities; reduced oxygen increased toxicity.
Lebistes reticulatus (guppy)	Crandall & Goodnight (1962)	1.5 mg/liter retarded growth, increased mortality and delayed sexual maturity; twice this concentration still did not cause 50% mortality.
Fundulus heteroclitus (killifish)	Eisler (1967)	157-180 mg/liter caused death of all fish in 24-48 hrs.; all were alive at 192 hrs. in 43 mg/liter; at 192 hrs., all survivors had the same zinc concentration in tissues regardless of the solution concentration
Pimephales promelas (fathead minnow)	Brungs (1969)	96 hr. TLm - 9.2 mg/liter. Chronic 10-month study at 2.8, 1.3, .66, .32, and .18 mg/liter: reproduction was inhibited from 2.8 to .32 mg/liter; at 1.3, .66, and .32 mg/liter typical spawning behavior was observed, but spawning was infrequent; growth was reduced at 2.8 mg/liter only; the number of eggs per female was reduced in even the lowest concentration. .18 mg/liter.

Table 5 (continued)

Organism	Reference	Toxicities and Comments
Pimephales promelas	Pickering & Vigor (1965)	24 hr. TLm to eggs > 3.98 mg/liter; decreased to 1.68 mg/liter after 12 days exposure. 24 hr. TLm to fry = .95 mg/liter; decreased to .87 after 7 days exposure. 100% fry survival at .56 mg/liter.
Brachydanio rerio (zebrafish)	Skidmore (1965)	11 age groups at four concentrations (5-40 mg/liter) in soft water: resistance of juveniles and adults was slightly greater in high concentrations and much greater at lower concentrations.
Brachydanio rerio (zebrafish)	Skidmore (1967)	Resistance to zinc (measured as survival time) is inversely proportional to oxygen uptake at any one age; survival period for any one concentration is related to dry weight.
Salmo gairdnerii (rainbow trout)	Sprague (1968)	Avoidance reaction to sublethal concentrations of zinc sulphate; threshold avoidance level was 5.6 mg Zn/liter which is .01 of the lethal level. The threshold did not change with temperature or increased background zinc
Lepomis macrochirus (bluegill)	Pickering (1968)	Low dissolved oxygen concentrations; increased mortality to zinc
Nine fish species	Chapman (1973)	Review of literature for zinc toxicity in soft water; 96 hr LC_{50} ranged from 90 ppb for *Salmo clarki* to 6440 ppb for *Crassius auratus*

b. Mercury

The toxicity of mercury to organisms is well documented. There is some apprehension that man has upset the natural cycling of mercury by contributing significantly to mercury levels found in nature. There have been a number of recent mercury related: symposia (Royal Society of Canada, 1971; Oregon State University, 1972; National Research Council of Canada, 1974), books (D'Itri, 1972; Friberg and Vostal, 1972) and review articles (Gavis and Ferguson, 1972; Peakall and Lovett, 1972; Wood, 1974).

Much of the early toxicity literature was reviewed by McKee and Wolf (1963); this is summarized in Table 6 along with more recent studies. As in the zinc studies, these are toxicities of mercury in the water column and most are studies of acute toxicity.

Mercury is equally toxic to mayflies, stoneflies and caddisflies (Warnick and Bell, 1969); it was the most toxic of the nine metals studied. Mercury was more toxic than copper, zinc or nickel to several species of marine invertebrates (Portman, 1968). Biesinger and Christensen (1972) determined that a chronic mercury exposure for <u>Daphnia</u> permitted survival but impaired reproduction and weight gain. Brown shrimp tolerance increased by a factor of five with temperature reduced from 22°C to 5°C (Portman, 1968). Shrimp resistance increased with age. Rainbow trout tolerate higher concentrations and accumulate smaller amounts of mercury at low

temperatures.

Responses of organisms to mercury are species-dependent. While mercury levels as low as .001 ppm prevent growth and photosynthesis in certain phytoplankton, some fish withstand up to 1 ppm mercury (Harriss et al., 1970; Harriss, 1970). Differing toxicities to species of zooplankton crustaceans are related to the rate of mercury accumulation in tissues rather than to variable tissue tolerances (Corner and Sparrow, 1957; Corner and Rigler, 1958).

The half-retention time in tissues of rainbow trout after a single oral dose of methyl mercury was estimated to be greater than 200 days (Giblin and Massaro, 1973).

Different life stages of a species may have varying sensitivities to mercury. Larval fiddler crab seem to show less resistance with age (DeCoursey and Vernberg, 1972). Elder and Gaufin (1974) suggest that aquatic insects are more sensitive to mercury during early instars and period of molting. Embryonic fish were extremely sensitive to small amounts of mercury (Birge and Just, 1975).

There are several studies of sublethal effects of mercury on organism behavior. DeCoursey and Vernberg (1972) demonstrated sublethal effects of mercury on larval fiddler crab metabolism and activity behavior. Alexander (1974) measured sublethal effects of mercury on swimming performance and respiration of rainbow trout. The results suggested that the exposure and/or uptake of mercury by trout could

impair its ability to perform burst swimming speeds or high sustained speeds.

The ability of mosquitofish to avoid predation by bass was impaired after 24 hour exposures to sublethal mercury concentrations (Kania and O'Hara, 1974).

Table 6. Toxicity of mercury in water to aquatic organisms. Mercury was in the inorganic form unless otherwise indicated.

Organism	Reference	Toxicities and Comments
Protozoa		
Tetrahymena pyriformis	Carter & Cameron (1973)	96 hr TLm = 4.5 mg/liter
Crustacea		
Daphnia	Biesinger & Christensen (1972)	48 hr. LC_{50} = .005 mg/liter without food. 3 week LC_{50} = .013 mg/liter. 3 week 50% reproductive impairment = .0067 mg/liter. 3 week 16% reproductive impairment = .0034 mg/liter.
Pandalus montagui (pink shrimp)	Portman (1968)	48 hr. TL_{50} = 0.1 mg/liter
Crangon crangon (brown shrimp)	Portman (1968)	48 hr. TL_{50} = ~6.0 mg/liter
Carcinus maenus (shore crab)	Portman (1968)	48 hr. TL_{50} = ~1.0 mg/liter
Gammarus	Rewholdt et al. (1973)	24 hr TLm - .09 ppm; 96 hr TLm = .01 ppm
Stages I, II, V of larval *Uca pugilator*	DeCoursey & Vernberg (1972)	No Stage V and few Stage I or III survived .18 mg/liter longer than 24 hr. Sublethal concentrations (.0018 and .000018) affected metabolism and swimming.
Insecta		
Acroneuria lycorias (stonefly)	Warnick & Bell (1969)	96 hr. TLm = 2.0 mg/liter

Table 6 (continued)

Organism	Reference	Toxicities and Comments
Insecta (continued)		
Ephemerella subvaria (mayfly)	Warnick & Bell (1969)	96 hr. TLm = 2.0 mg/liter
Hydropsyche betteni (caddisfly)	Warnick & Bell (1969)	96 hr. TLm = 2.0 mg/liter
Pteronarcys californica	Elder & Gaufin (1974)	TLm values: phenylmercuric chloride>metayl-mercuric chloride >mercuric chloride
Mollusca		
Cardium edule (cockle)	Portman (1968)	48 hr. TL_{50} = ~10.0 mg/liter
Pisces		
fish	review by McKee & Wolf (1963)	Concentrations from .008 to 5000 mg/liter have been reported as *harmful* or lethal (12 studies below 0.2 mg/liter; 7 from 3.2-12.6 mg/liter; 1 each at 30.0, 370, 1000 and 5000 mg/liter.
Salmo gairdneri (rainbow trout)	MacLeod & Pessah (1973)	96 hr. TLm = 0.40 mg/liter at $5^{0}C$, 0.28 mg/liter at $10^{0}C$, and 0.22 mg/liter at $20^{0}C$.

Table 6 (continued)

Organism	Reference	Toxicities and Comments
Pisces (continued)		
Salmo gairdneri (rainbow trout)	Alexander (1974)	96 hr LC_{50} = .205 mg/liter at 15°C. Active rate[1], fatigue velocity[2], and scope for activity[3] decreased significantly within the concentration range of 0.050-0.144 mg/liter while the standard rate of metabolism increased; fatigue velocity decreased significantly with mercury conc. in gill and muscle tissue.
Mosquitofish (*Gambusia affinis*)	Kania and O'Hara (1974)	24 hr. exposure to 0.1, .05 and .01 mg/liter reduced the ability of mosquitofish to avoid predation by bass; .005 mg/liter had no effect.
Embryos of rainbow trout, channel catfish and goldfish	Birge and Just (1975)	.01 mg/liter produced mortality rates of 66%, 12% and 2% respectively with methyl mercury; .05 and .02 mg/liter caused lethality or severe abnormalities in 53% and 23% of trout embryos. .001 mg/liter caused 10-22% mortality to trout embryos as inorganic or methyl mercury.

[1] Measured indirectly by heat loss

[2] Highest velocity attainable with incremental increase in velocity (an index of swimming performance)

[3] The difference between standard (at rest) and active metabolic rates

D. Summary and Evaluation of Literature.

1. The burrowing amphipod *Pontoporeia affinis* is the predominant member of the macrobenthic community in all of the Great Lakes, and it is a base to the food web leading to numerous economically important fishes.
2. Nothing is known about heavy metals in the food chain involving *Pontoporeia*. Information on metals in any benthic food chain is scarce.
3. There have been no studies on the effects of specific pollutants on *Pontoporeia*. The main effect described in the literature is on relative abundance (i.e., increased oligochaetes and fewer *Pontoporeia* with organic enrichment).
4. There is no information on acute or chronic effects of metals on survival, growth, reproduction, or behavior of *Pontoporeia*. Very little is known about chronic effects of pollutants on any benthic invertebrate.
5. All previous metal toxicity experiments consider the water column; they do not consider the sediments.
6. Nearly all reports considering biological and ecological effects of dredging and spoil disposal state that each site is unique and must be evaluated individually. Sediment character in the dredge spoil area, biological communities, physical and chemical properties of the water, currents and disposal technique are all important in making such evaluations.

7. Long term effects of dredging and disposal operations are not well understood.
8. Microcontaminants such as the heavy metals have been investigated very little in studies of dredging and disposal operations.

II. Field Study - Benthic Macroinvertebrates at Duluth-Superior

A. Introduction

Distributions of benthic macroinvertebrates in the Duluth-Superior region of Lake Superior were surveyed. Metal concentrations determined for sediments, Pontoporeia, and fish from Lake Superior are included in Volume 5.

B. Materials and Methods

Benthic invertebrates were sampled at Duluth-Superior harbor in October, 1973; at Allouez Bay in September, 1974; at the old dump sites in the Lake in September, 1973 and October, 1974; at the nearshore area of the lake near Superior Entry in July, 1974; along a transect out from Superior Entry and two perpendicular transects in October, 1974 and finally, in May, 1975 to prepare an extensive map off both entries on a one-mile grid including both old dump sites.

Bottom samples were collected with a standard 9" X 9" Ponar dredge fitted with number 30 stainless steel bolting cloth screens. Stations were located with a mini-ranger or sextant. We sampled from a 21-foot Boston Whaler and UW-Superior's 35-foot tugboat. Boats were equipped with a winch to raise and lower the Ponar dredge. Three dredge hauls per station were made for biological analysis. Each dredge sample was bagged and sieved separately. An additional Ponar sample was taken for a qualitative sediment analysis. Bottom and surface temperatures and depth were recorded.

Through September, 1974, samples were transferred to Trout Lake Biological Station of UW-Madison in Vilas Co., Wisconsin. Samples were

kept cool until processed within one week of collection. Samples were sieved through a 6 X 6 mesh stainless steel screen (.047 inch diameter wire, 3.05 mm opening) to remove small stones, sticks and other debris. The remaining portion was then sieved through 16 X 16 mesh stainless steel screen (.028 inch diameter wire, 0.89 mm opening). Organisms were picked from the screen and preserved in 70% alcohol. In October, 1974 and May, 1975 all samples were sieved and the organisms and coarse sediments and detritus decanted into jars and preserved within 48 hours. Organisms were later sorted in the laboratory; the jar was emptied into a white tray and each organism was tallied as Pontoporeia, oligochaete, chironomid or sphaeriid. Chironomid larvae and pupae were counted together. Other invertebrates were noted and preserved but not counted - these were Mysis relicta which our sampling technique was not designed to collect, adult dipterans which may have been caught from the surface, and a few minute ostracods.

C. Results

Distribution of benthic macroinvertebrates are summarized in maps and tables and in appendix tables. Appendices include numbers in each Ponar dredge, average number/m^2, standard deviation, and variance (for _Pontoporeia_, Oligochaeta, Chironomidae and Sphaeriidae) based on three Ponar dredges per station unless otherwise indicated, the per cent of the total organisms at each station contributed by each of the four groups and temperature, substrate type and depth.

Date	Location(s)	Figure or Table	Appendix
Oct. 16, 1973	Duluth-Superior Harbor & Allouez Bay	Table 7	
Sept. 10, 1974	Allouez Bay	Table 8	
Sept. 14 & 15, 1973 Oct. 14 & 15, 1973	Open lake - old dump sites	Table 9	
July 25-27, 1974	Open lake	Figures 2-5	A
Sept. 11, 1974	Open lake	Figures 8-11	B
Oct. 8 & 13, 1974	Open lake	Figures 12-15	C
May 22-28, 1974	Open lake	Figures 16-19	D

Maps of sediment type and bathymetry are included for May, 1975 (Figs. 18 and 19).

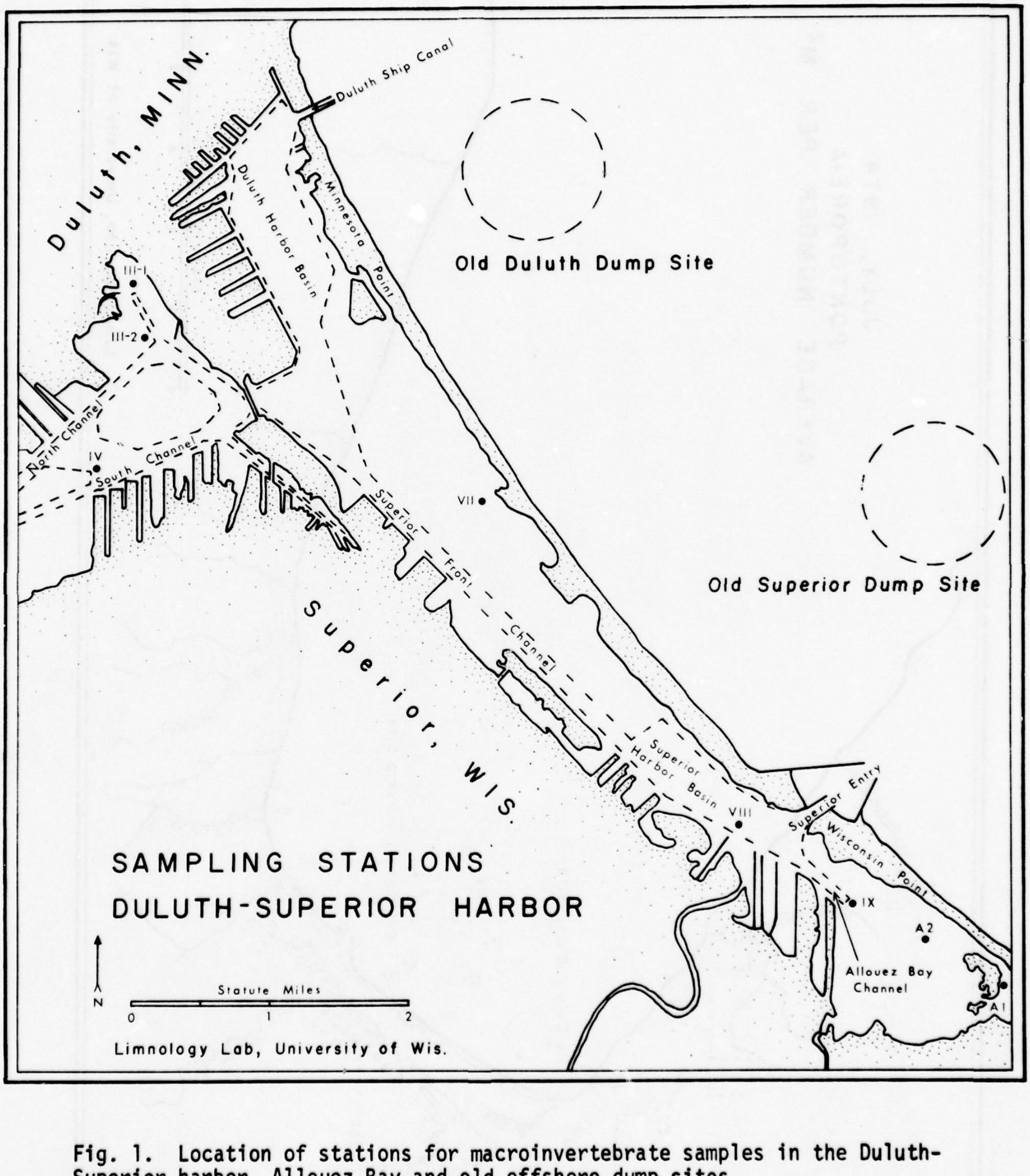
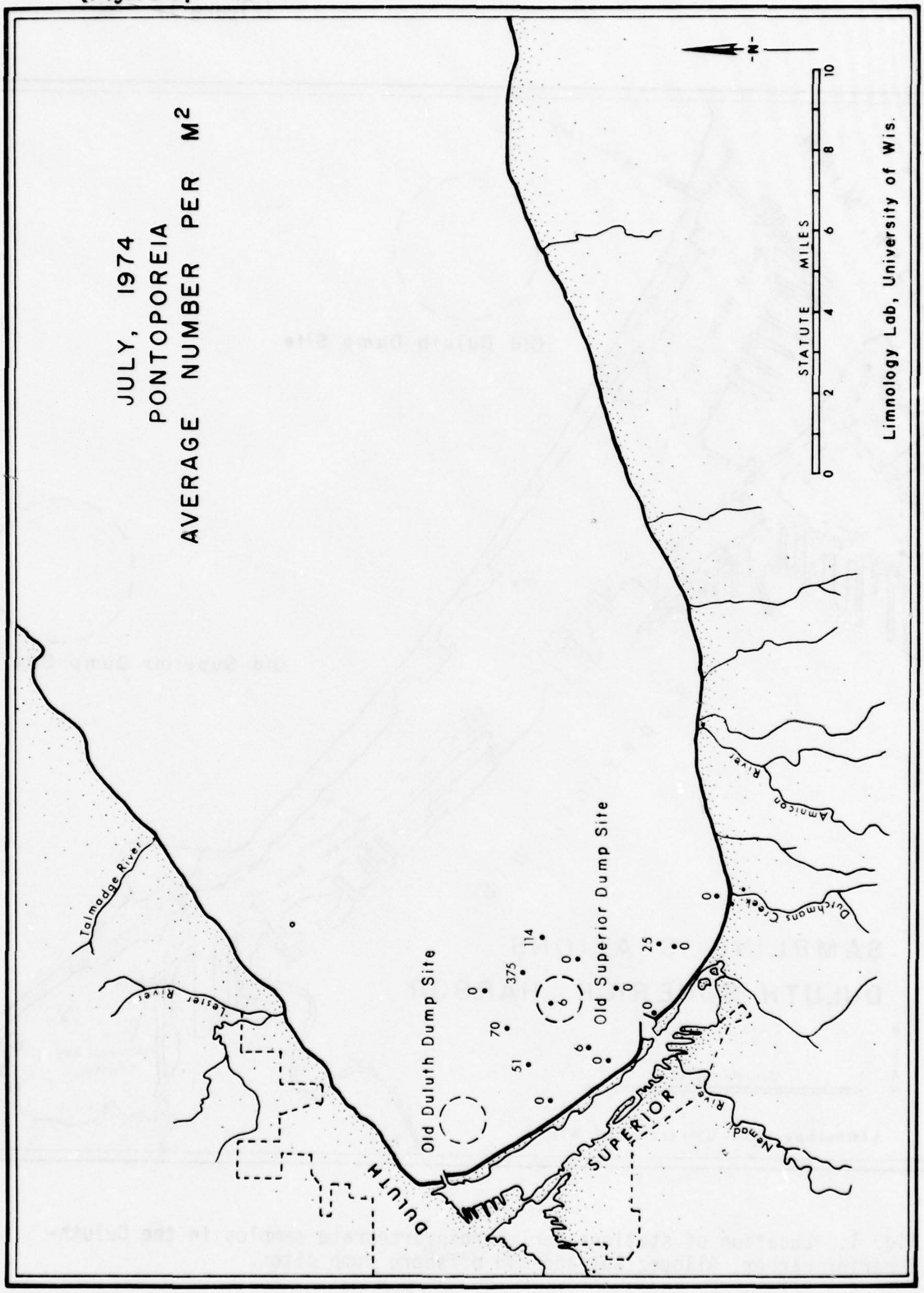
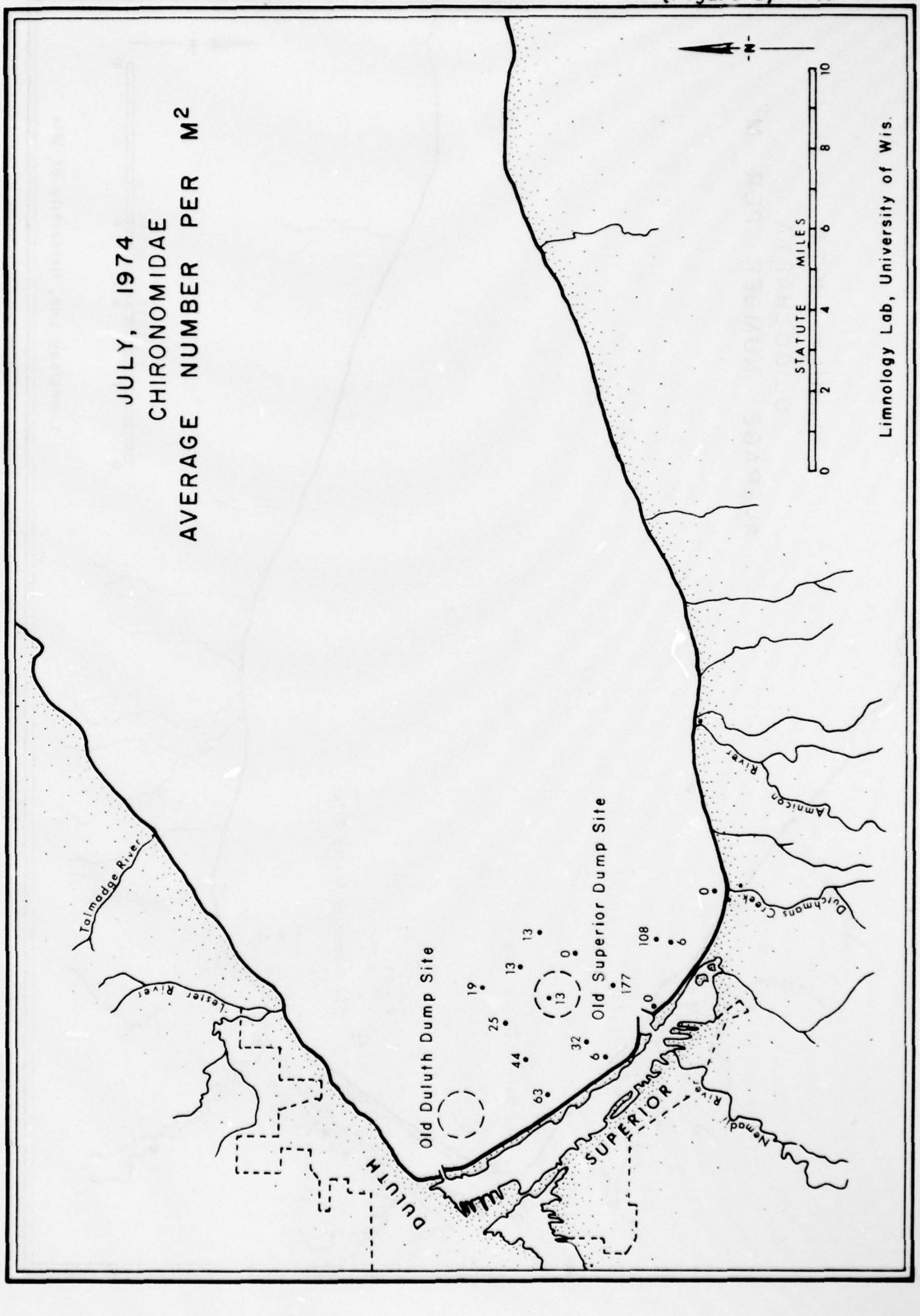
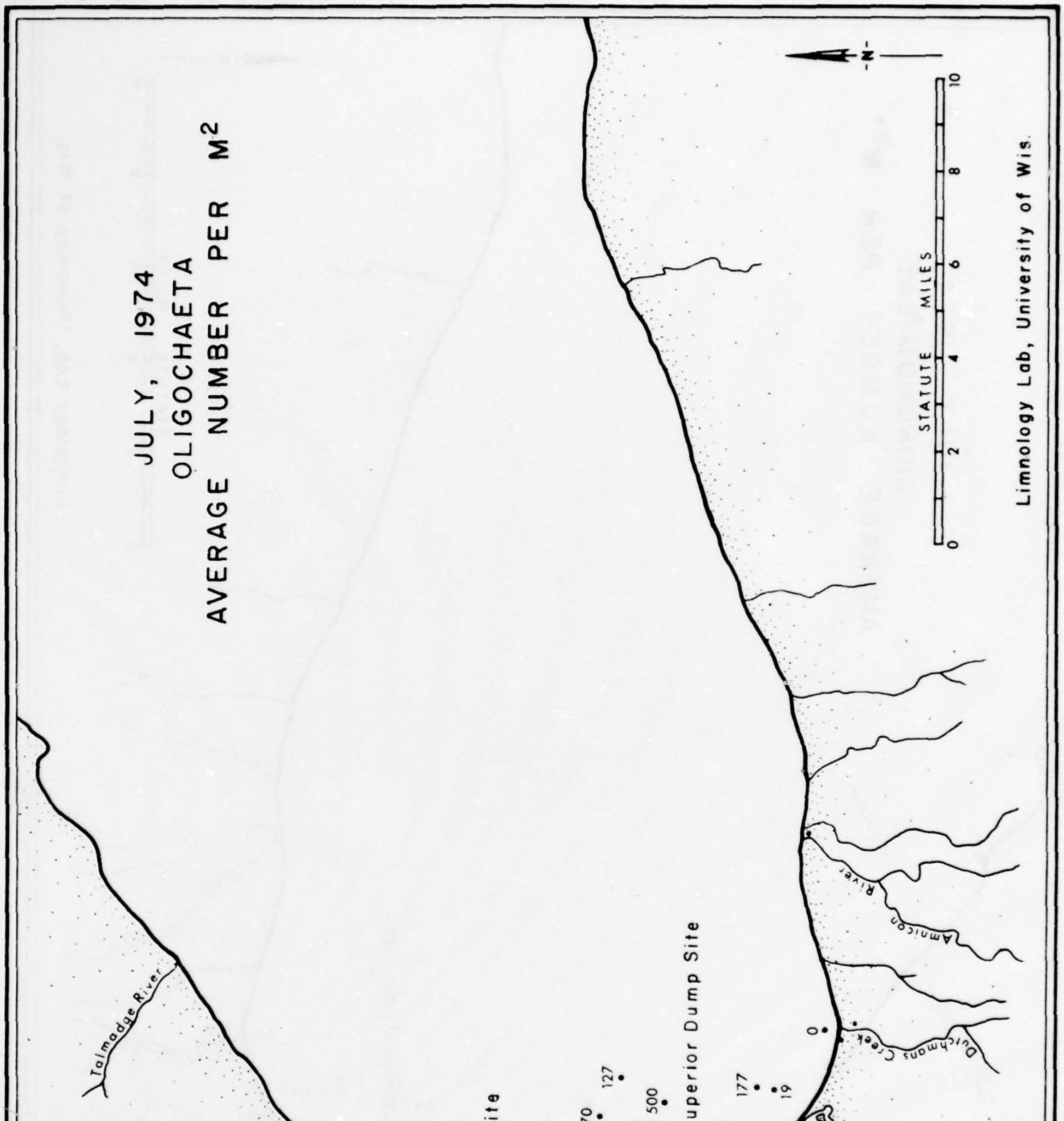
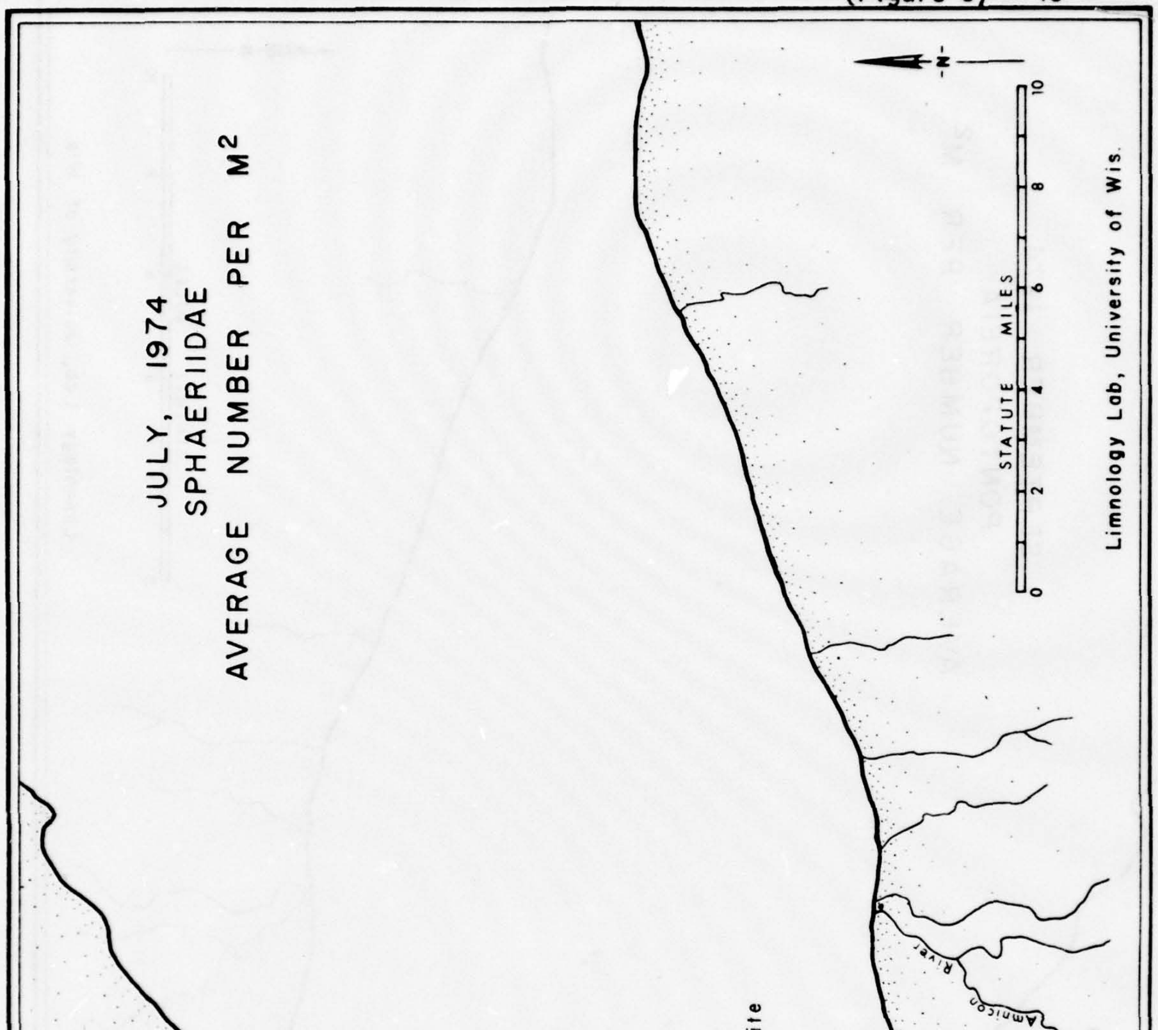


Fig. 1. Location of stations for macroinvertebrate samples in the Duluth-Superior harbor, Allouez Bay and old offshore dump sites.

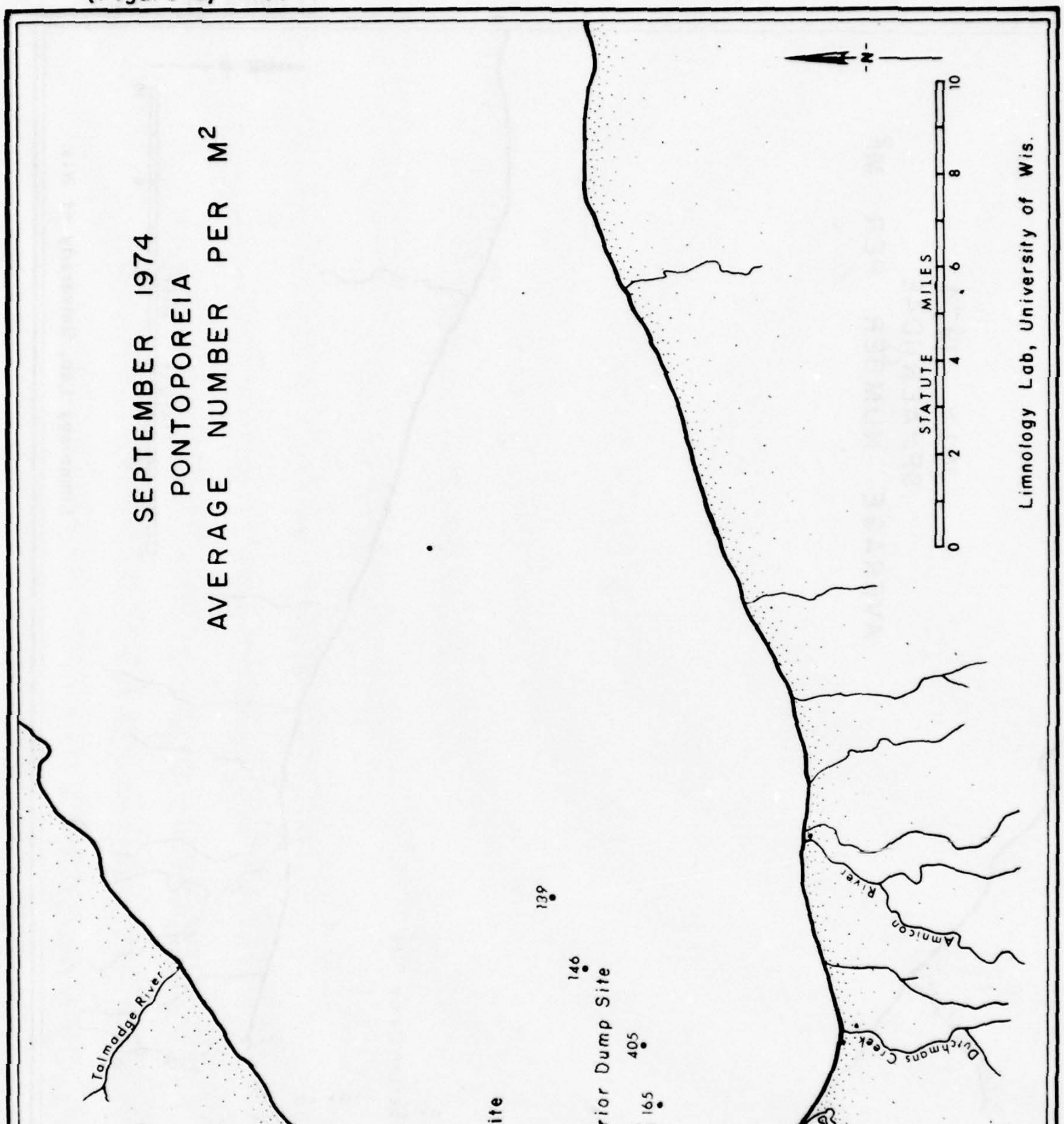

JULY, 1974
PONTOPOREIA
AVERAGE NUMBER PER M²
Talmadge River
Lester River
Old Duluth Dump Site
Old Superior Dump Site
Amnicon River
Dutchmans Creek
Nemadji River
DULUTH
SUPERIOR
51
70
375
114
25
10
STATUTE MILES
0 2 4 6 8 10
N
Limnology Lab, University of Wis.

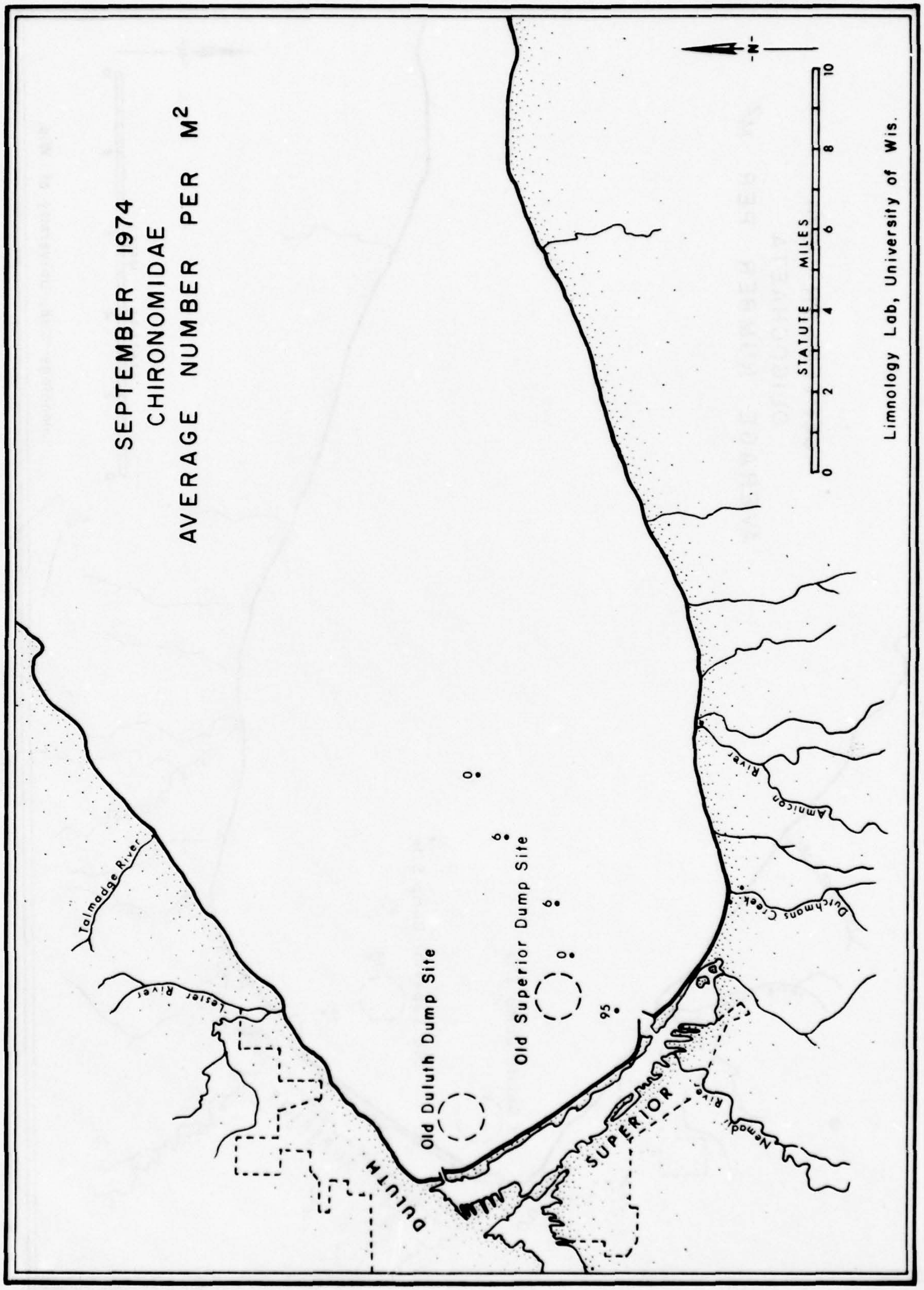

JULY, 1974
CHIRONOMIDAE
AVERAGE NUMBER PER M²
Talmadge River
Lester River
Amnicon River
Dutchmans Creek
Nemadji River
DULUTH
SUPERIOR
Old Duluth Dump Site
Old Superior Dump Site
63
44
6
32
25
19
13
13
13
0
177
0
108
6
6
0
N
STATUTE MILES
0
2
4
6
8
10
Limnology Lab, University of Wis.

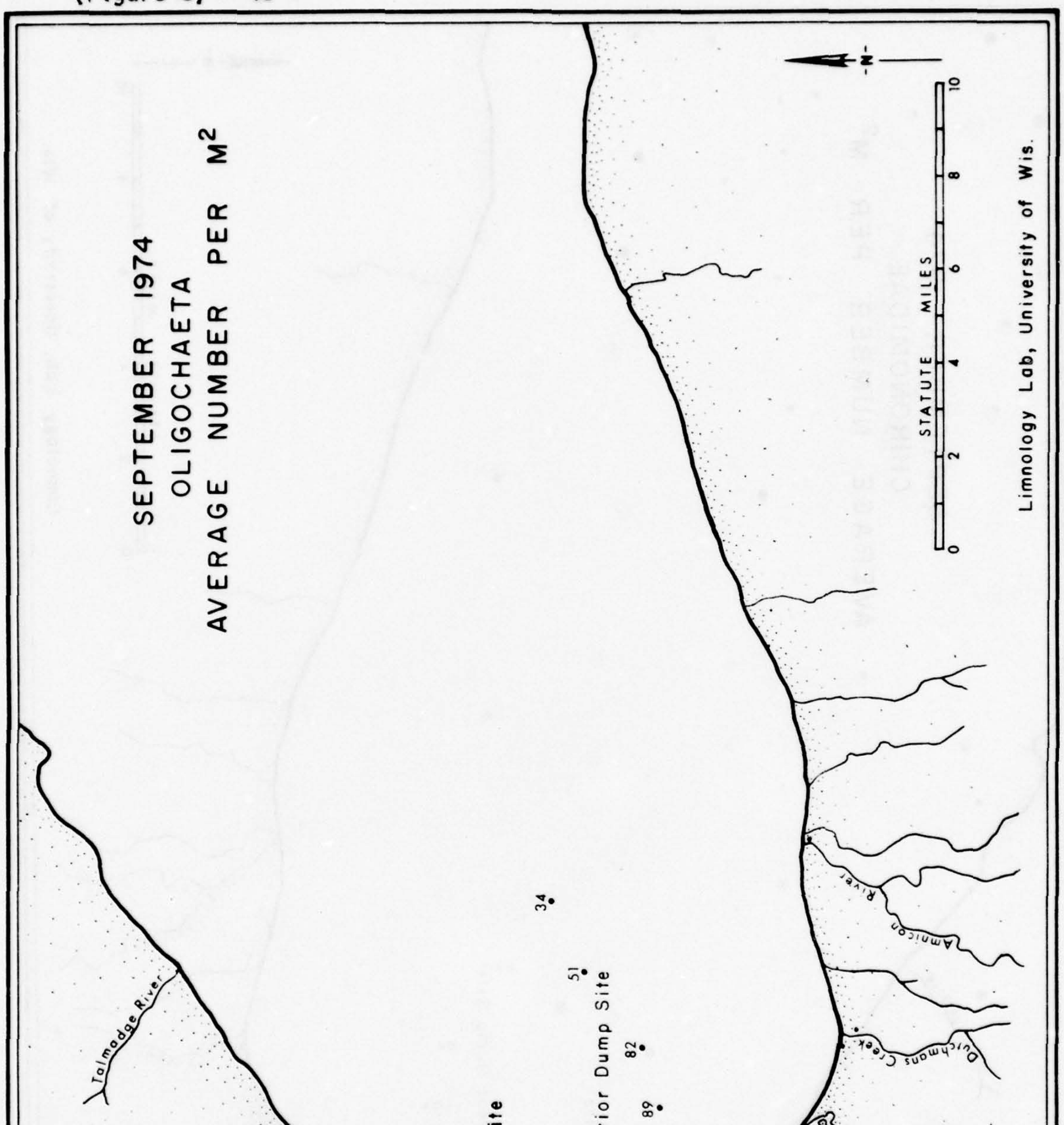

JULY, 1974
OLIGOCHAETA
AVERAGE NUMBER PER M²
N
STATUTE MILES
0 2 4 6 8 10
Limnology Lab, University of Wis.
Talmadge River
Lester River
Amnicon River
Dutchmans Creek
DULUTH
SUPERIOR
Old Duluth Dump Site
Old Superior Dump Site
0
405
177
120
70
127
431
6
361
500
798
0
177
19
0

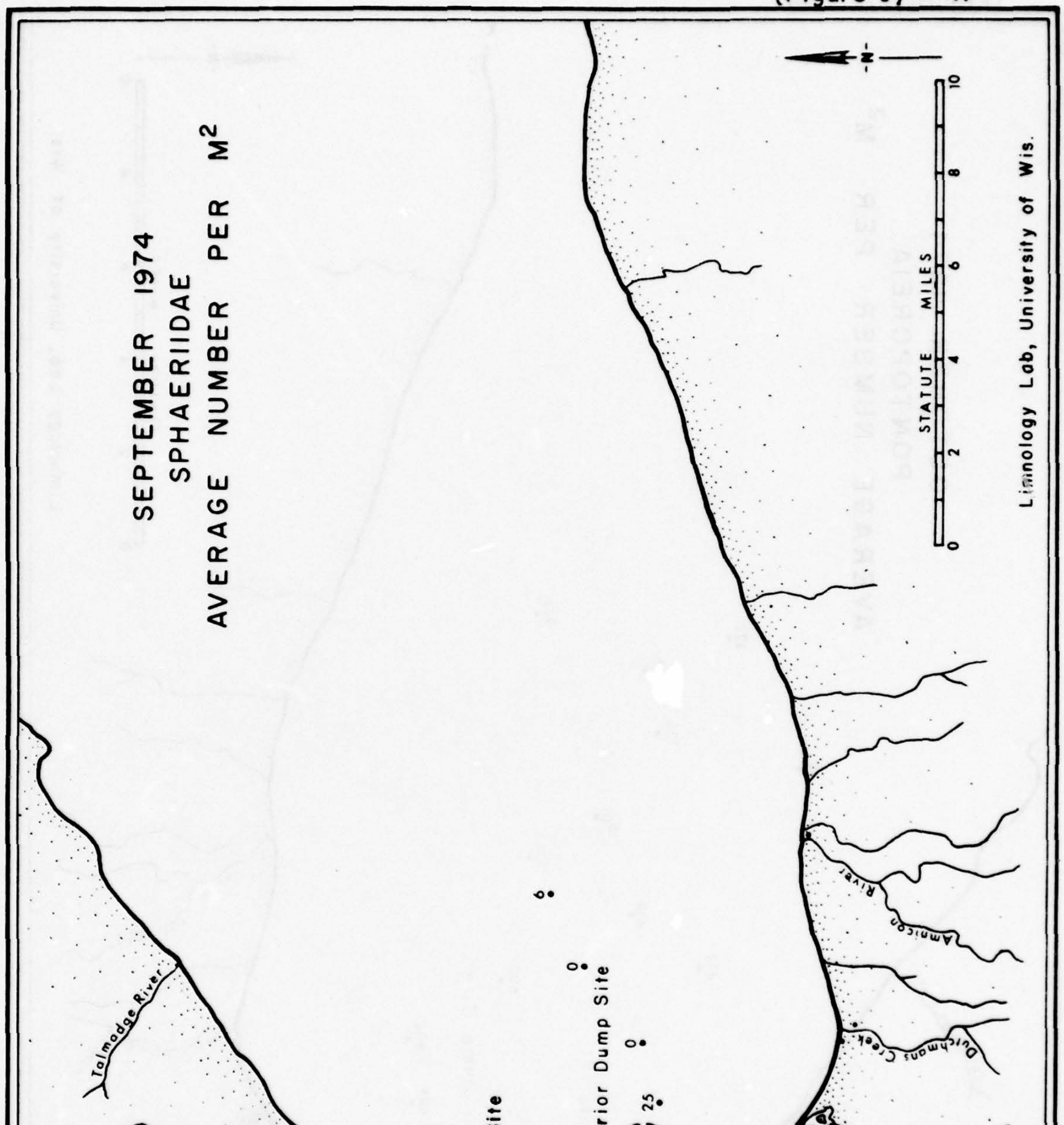

JULY, 1974
SPHAERIIDAE
AVERAGE NUMBER PER M²
Old Duluth Dump Site
Old Superior Dump Site
Talmadge River
Lester River
Amnicon River
Duchmans Creek
Nemadji River
DULUTH
SUPERIOR
STATUTE MILES
0 2 4 6 8 10
N
Limnology Lab, University of Wis.

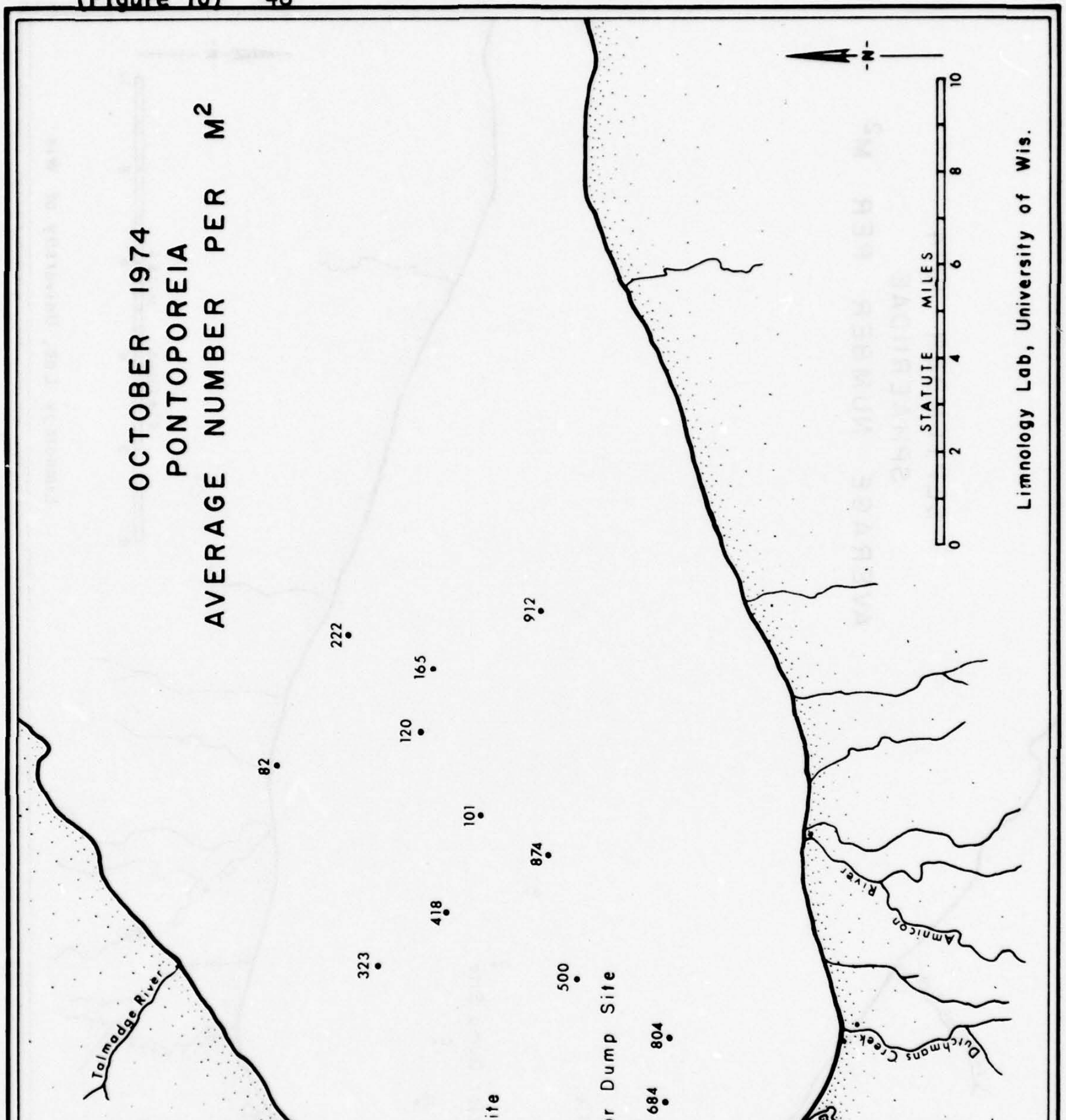
(Figure 6)

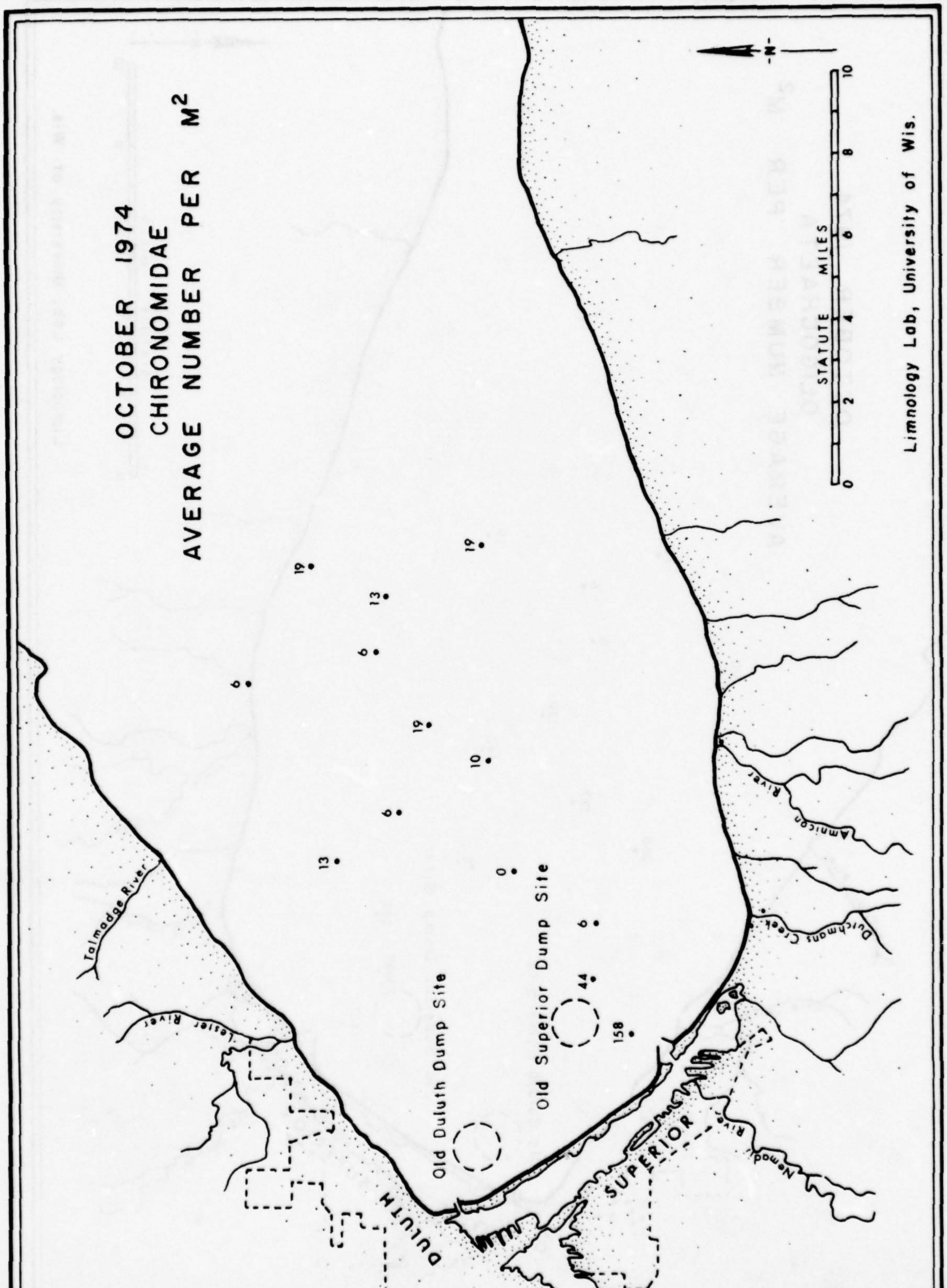

SEPTEMBER 1974
PONTOPOREIA
AVERAGE NUMBER PER M²
STATUTE MILES
0 2 4 6 8 10
N
Limnology Lab, University of Wis.
Old Duluth Dump Site
Old Superior Dump Site
139
146
405
165
133
Talmadge River
Lester River
Amnicon River
Dutchmans Creek
Nemadji River
DULUTH
SUPERIOR

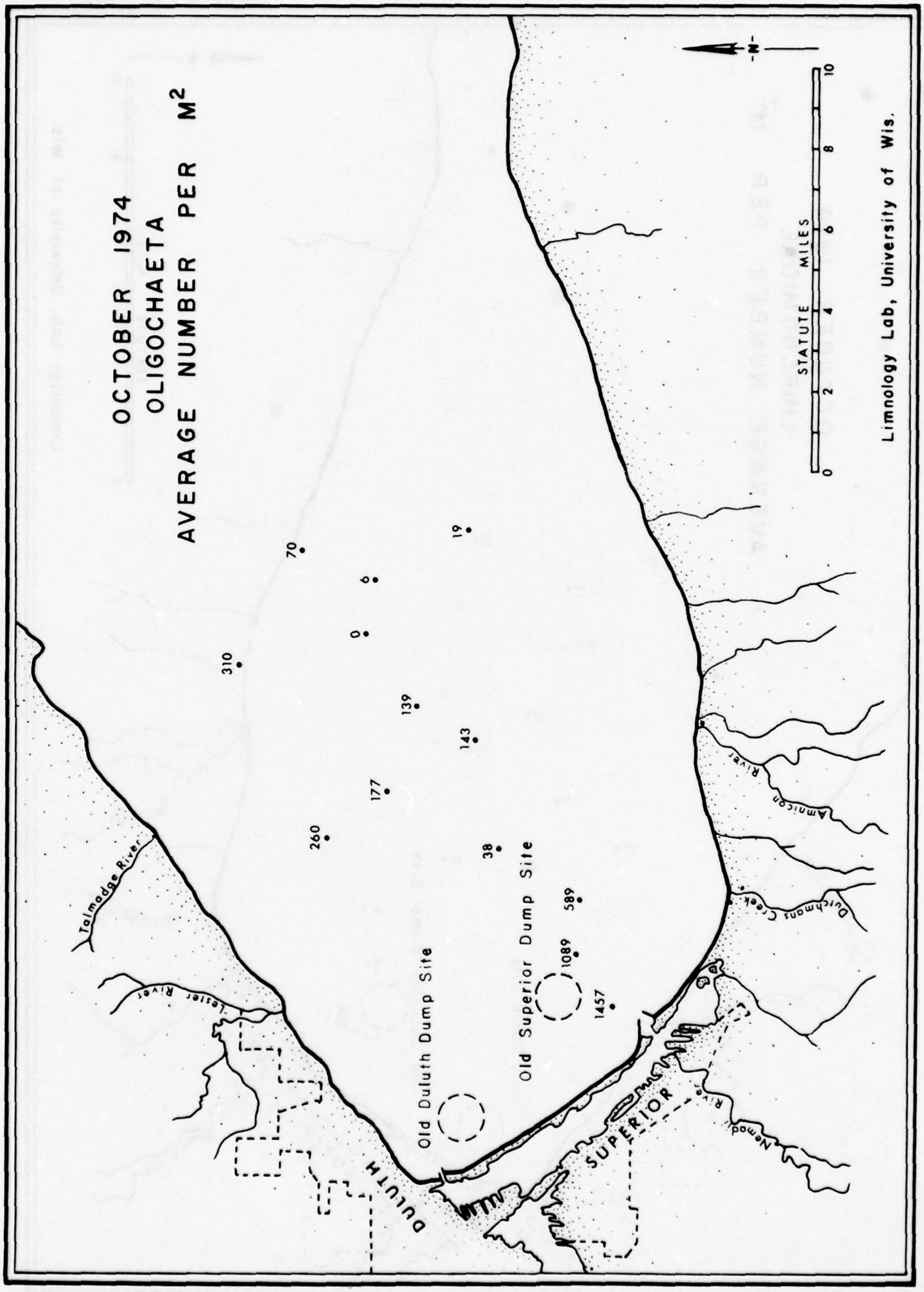

SEPTEMBER 1974
CHIRONOMIDAE
AVERAGE NUMBER PER M²
Old Duluth Dump Site
Old Superior Dump Site
0
6
6
0
95
Talmadge River
Lester River
Amnicon River
Dutchmans Creek
Nemadji River
DULUTH
SUPERIOR
N
STATUTE MILES
0
2
4
6
8
10
Limnology Lab, University of Wis.

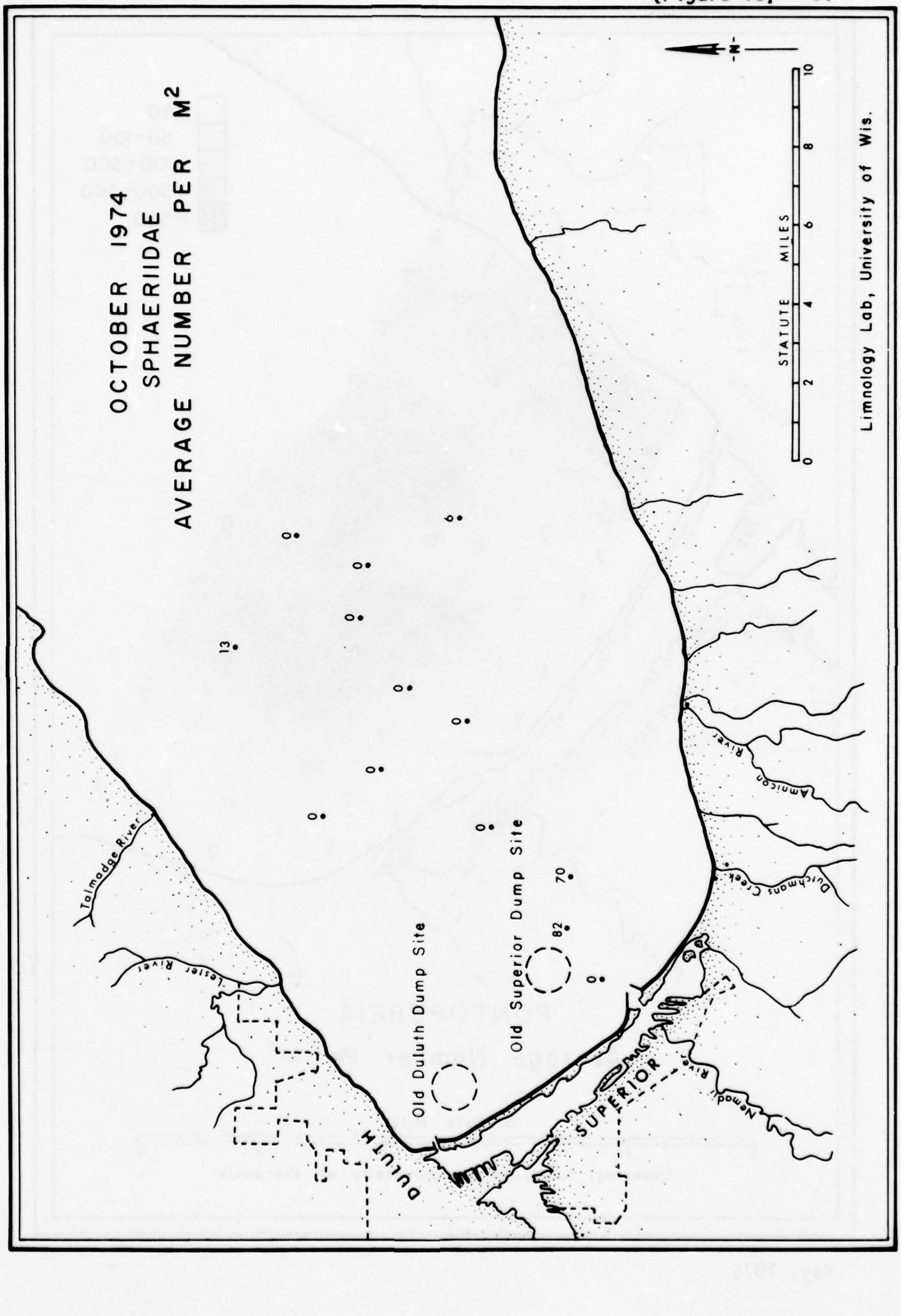

SEPTEMBER 1974
OLIGOCHAETA
AVERAGE NUMBER PER M2
N
STATUTE MILES
0 2 4 6 8 10
Limnology Lab, University of Wis.
Talmadge River
Lester River
Amnicon River
Dutchmans Creek
Nemadji River
DULUTH
SUPERIOR
Old Duluth Dump Site
Old Superior Dump Site
34
51
82
89
285


SEPTEMBER 1974
SPHAERIIDAE
AVERAGE NUMBER PER M^2
Old Duluth Dump Site
Old Superior Dump Site
133
25
0
0
6
DULUTH
SUPERIOR
Talmadge River
Lester River
Amnicon River
Dutchmans Creek
Nemadji River
N
0
2
4
6
8
10
STATUTE MILES
Limnology Lab, University of Wis.

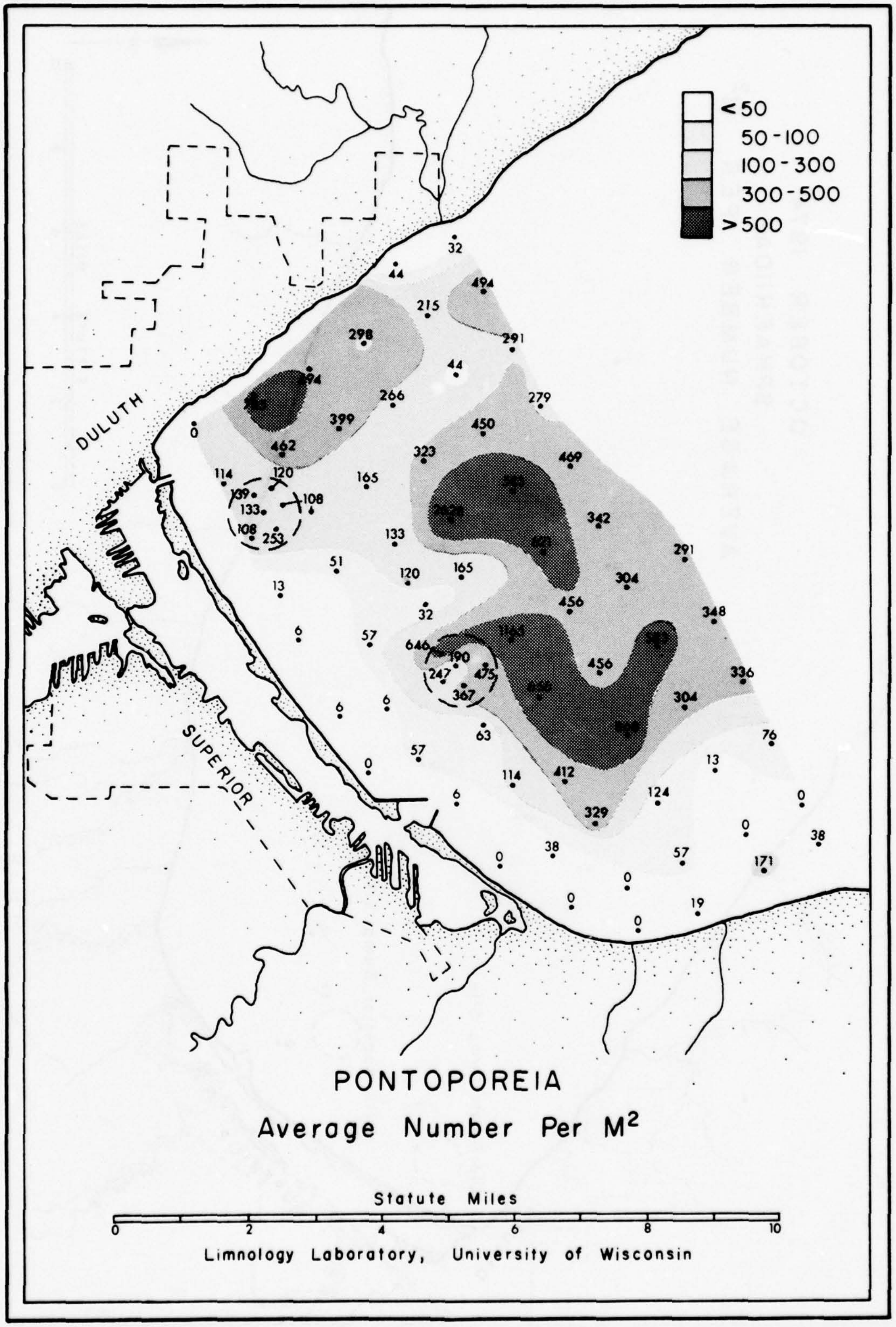

OCTOBER 1974
PONTOPOREIA
AVERAGE NUMBER PER M²
N
0 2 4 6 8 10
STATUTE MILES
Limnology Lab, University of Wis.
82
222
120
165
912
101
874
418
323
500
804
684
247
Old Duluth Dump Site
Old Superior Dump Site
Talmadge River
Lester River
Amnicon River
Duchmans Creek
Nemadji River
DULUTH
SUPERIOR


OCTOBER 1974
CHIRONOMIDAE
AVERAGE NUMBER PER M²
STATUTE MILES
0 2 4 6 8 10
N
Limnology Lab, University of Wis.
Talmadge River
Lester River
Amnicon River
Dutchmans Creek
Nemadji River
DULUTH
SUPERIOR
Old Duluth Dump Site
Old Superior Dump Site
19
13
6
6
19
10
6
13
0
6
44
158
19

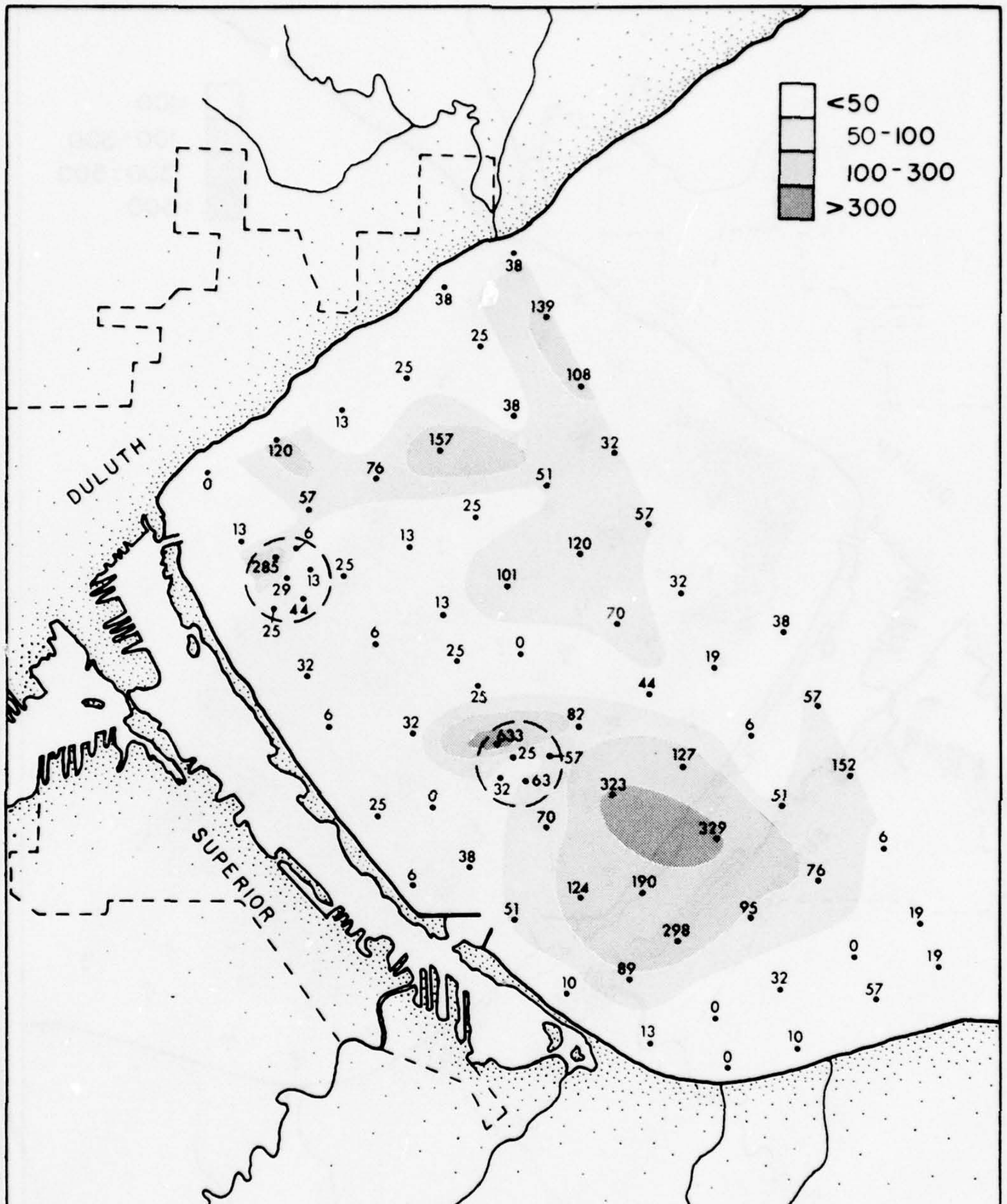

OCTOBER 1974
OLIGOCHAETA
AVERAGE NUMBER PER M²
310
0
9
70
19
139
143
177
260
38
589
1089
1457
Old Duluth Dump Site
Old Superior Dump Site
Talmadge River
Lester River
DULUTH
SUPERIOR
Nemadji River
Amnicon River
Dutchmans Creek
STATUTE MILES
0
2
4
6
8
10
N
Limnology Lab, University of Wis.


OCTOBER 1974
SPHAERIIDAE
AVERAGE NUMBER PER M²
N
STATUTE MILES
0 2 4 6 8 10
Limnology Lab, University of Wis.
Old Duluth Dump Site
Old Superior Dump Site
Talmadge River
Lester River
Amnicon River
Dutchmans Creek
Nemadji River
DULUTH
SUPERIOR
13
70
82
0

(Figure 14) 52

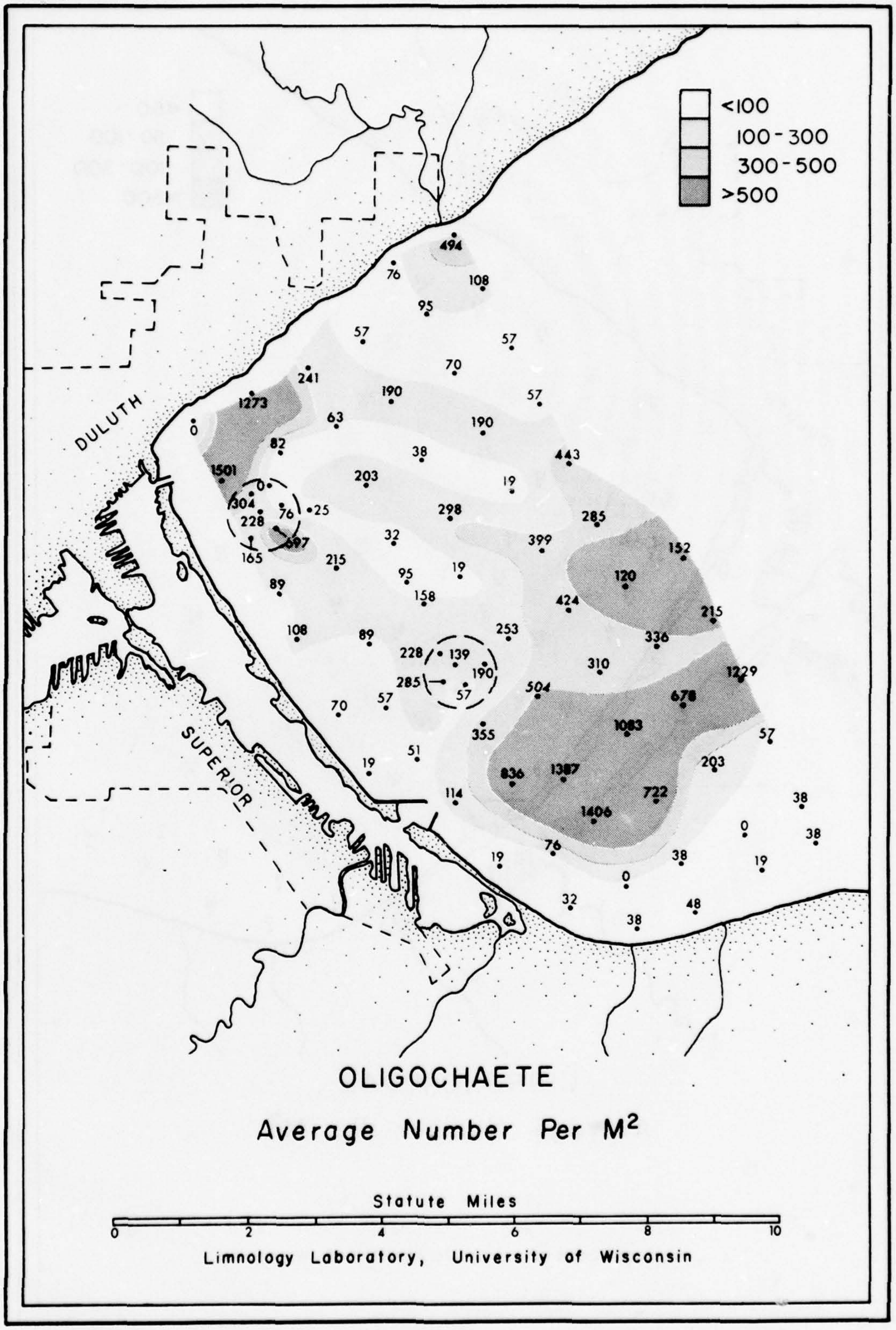


May, 1975

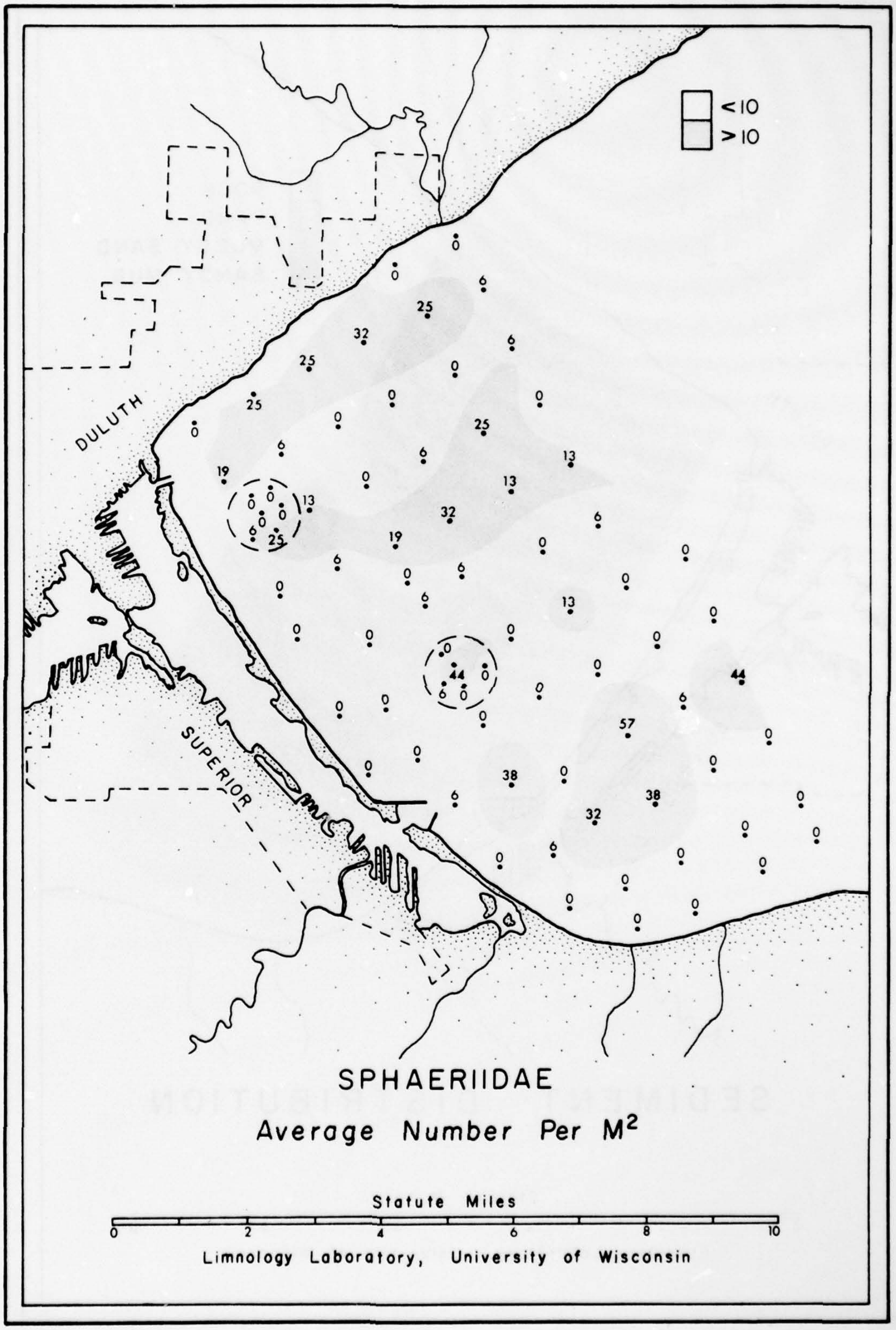


CHIRONOMIDAE
Average Number Per M^2

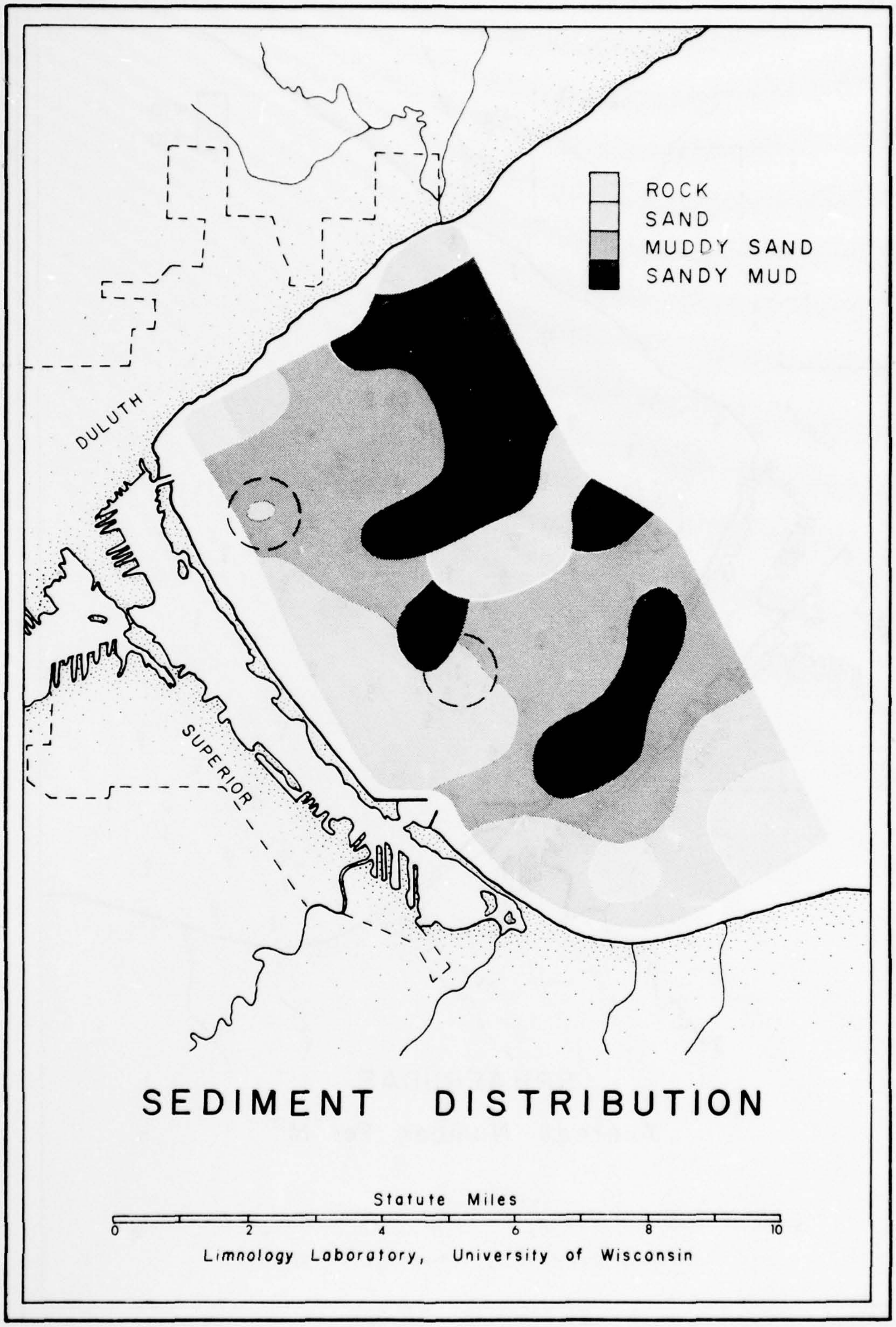
May, 1975


<100
100-300
300-500
>500
DULUTH
SUPERIOR
494
76
108
95
57
57
70
241
1273
190
57
0
63
190
82
38
443
1501
203
19
0
304
76
•25
228
298
285
697
32
399
152
165
215
19
89
95
120
158
424
215
108
89
253
336
228
139
310
190
1229
285
57
504
70
57
678
355
1083
57
51
19
203
836
1387
722
38
114
1406
0
38
76
19
38
19
0
32
48
38
OLIGOCHAETE
Average Number Per M²
Statute Miles
0
2
4
6
8
10
Limnology Laboratory, University of Wisconsin

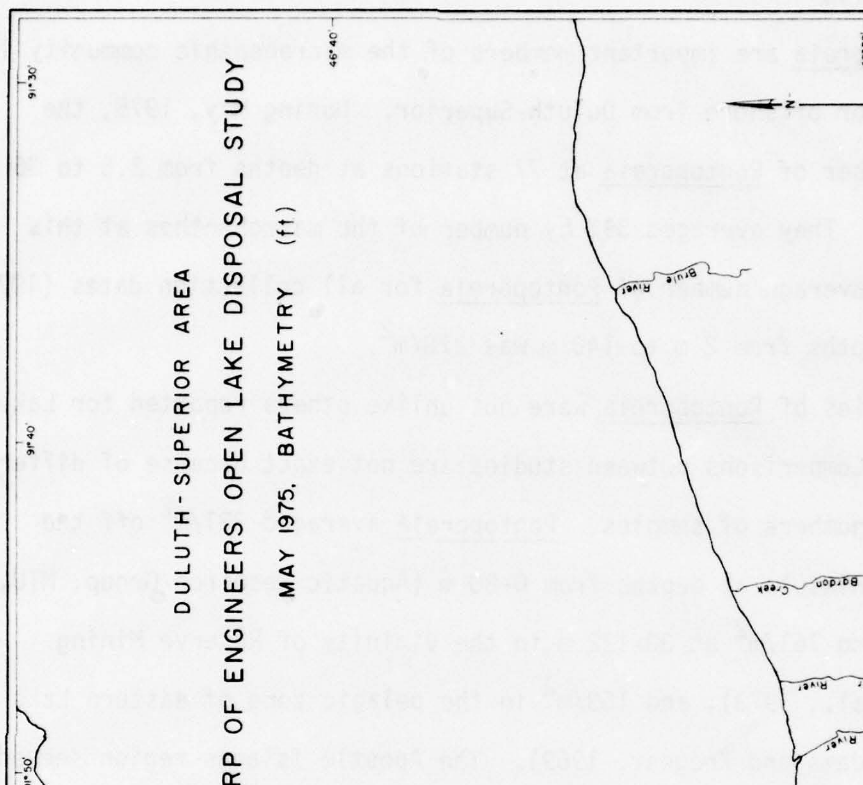
May, 1975


<10
>10
DULUTH
SUPERIOR
SPHAERIIDAE
Average Number Per M²
Statute Miles
0
2
4
6
8
10
Limnology Laboratory, University of Wisconsin

May, 1975


ROCK
SAND
MUDDY SAND
SANDY MUD
DULUTH
SUPERIOR
SEDIMENT DISTRIBUTION
Statute Miles
0
2
4
6
8
10
Limnology Laboratory, University of Wisconsin

May, 1975


DULUTH - SUPERIOR AREA
CORP OF ENGINEERS OPEN LAKE DISPOSAL STUDY
MAY 1975, BATHYMETRY (ft)
METERS
STATUTE MILES
UNIVERSITY OF WISCONSIN Marine Studies Center
Brule River
Bardon Creek
Poplar River
Middle River
Amnicon River
Morrison Creek
Dutchmans Creek
Nemadji River
Lester River
Talmadge River
SUPERIOR
DULUTH
91°30'
91°40'
91°50'
92°00'
46°40'
46°30'

D. Discussion

Pontoporeia are important members of the macrobenthic community in Lake Superior offshore from Duluth-Superior. During May, 1975, the average number of *Pontoporeia* at 77 stations at depths from 2.5 to 36 m was 302/m^2. They averaged 39% by number of the macrobenthos at this time. The average number of *Pontoporeia* for all collection dates (1973-1975) at depths from 2 m to 140 m was 278/m^2.

Densities of *Pontoporeia* were not unlike others reported for Lake Superior. Comparisons between studies are not exact because of differing depths and numbers of samples. *Pontoporeia* averaged 331/m^2 off the Keweenaw Peninsula at depths from 0-80 m (Aquatic Research Group, MTU, 1975); 194 to 761/m^2 at 30-122 m in the vicinity of Reserve Mining (Henson et al., 1973); and 153/m^2 in the pelagic zone of eastern Lake Superior (Adams and Kregear, 1969). The Apostle Islands region seemed to support slightly higher *Pontoporeia* populations. Reported averages were 828/m^2 from 9-114 m (Hiltunen, 1969) and 878/m^2 from 5-95 m (Selgeby, personal communication). The benthos of an extensive portion of northern Lake Superior including Thunder Bay and Nipigon Bay have been surveyed; *Pontoporeia* were widely distributed, but their densities were not reported (Freitag et al., 1973).

Although our sampling was extensive only in May, 1975, *Pontoporeia* were conspicuously absent at inshore stations in midsummer (Figure 2) as compared to fall and spring (Figures 6, 10, 14). The average number of *Pontoporeia* collected in the inshore area in July, 1974 (15 stations, Figure 2) was 43/m_2. Stations visited in the same region in September, 1973 (five stations), October, 1973 (three stations), September, 1974 (two stations), October, 1974 (three stations) and May, 1975 (22 stations)

had $590/m^2$, $153/m^2$, $149/m^2$, $578/m^2$, and $344/m^2$, respectively. This suggests an offshore migration of Pontoporeia in midsummer when inshore temperatures were warmer. This migration is also suggested by Smith (1972). Biologists at Michigan Technological University did not find evidence for inshore/offshore seasonal movements of Pontoporeia at the Keweenaw Peninsula (Aquatic Research Group, MTU, 1975).

The Chironomidae (midges) and oligochaetes (annelid worms) were abundant off the Superior Entry at all times of the year (Figs. 3-4, 7-8, 11-12, 15-16). Sphaeriids (fingernail clams) were always low in number (Figs. 5, 9, 13, 17).

Sampling was extensive enough only in May, 1975 to contour the distribution of benthic organisms and related parameters (Figs. 14-19). Chironomids and oligochaetes seemed to concentrate in regions off the Superior and Duluth entries although their distribution was complex. This may reflect input from the Nemadji and St. Louis Rivers in combination with frequent lake seiches which exchange harbor and lake water. All four groups of organisms were abundant on muddy sand or sandy mud, and uncommon or absent on the coarser sediment of the immediate inshore zone. Current patterns and wave action determine the distribution of sediments in the lake and, thus, play a major role in determining organism distribution. The current patterns and wave action in western Lake Superior are discussed in Volume 4 of this report. The dynamics of sediment distribution are discussed in Volume 2.

The limited sampling in the Duluth-Superior harbor and Allouez Bay (Tables 7 and 8) revealed extremely high concentration of oligochaetes

in the region near the Duluth sewage outfall. Most of this sampling took place in the first year of the study; in the following year, we focused nearly all of our attention on the lake ecosystem.

Pontoporeia exist in substantial numbers on the old dumpsites, particularly the Superior dumpsite. Average numbers of Pontoporeia ranged from 108 to 253/m^2 at six locations on the Duluth-dumpsite in May 1975 (Figure 14). The populations ranged from 190 to 646/m^2 on the Superior dumpsite at five locations. A great range in Chironomid populations was noted. On the Duluth dumpsite there were 13 to 285 Chironomids/m^2 and 32 to 633/m^2 on the Superior dumpsite. Similarly, Oligochaete were found to vary on the dumpsites; 0-697/m^2 on the Duluth site, 57-285/m^2 on the Superior site. Sphaeriidae on the dumpsites varied from 0-44/m^2; almost the magnitude of variation found in the lake near Duluth-Superior.

Some stations on the old dumpsites had relatively high population densities of Pontoporeia, Chironomidae, Oligochaete, and Sphaeriidae similar to other areas of the lake near Duluth-Superior. There is no evidence to indicate that these animals avoid these sites of historic dredged material disposal.

Table 7. Benthic macroinvertebrates (number/m^2) in Duluth-Superior harbor, Oct., 1973. Each column represents numbers in one Ponar dredge sample converted to number/m^2. See Fig. 1 for location of stations in the harbor.

	Station											
	III-1		III-2		IV		VII		VIII		IX	
Turbellaria (flatworms)	0	0	0	0	19	0	0	19	0	0	0	0
Oligochaeta	22,891	4,000	20,231	94,705	574	2,010	555	287	823	1,493	210	115
Sphaeriidae (fingernail clams)	0	0	0	19	0	0	19	76	0	0	249	344
Gastropoda (snails)	19	0	0	0	0	0	0	0	0	0	0	0
Amphipoda (scuds)												
Gammarus	0	0	134	0	0	0	0	0	0	0	0	19
Pontoporeia	0	0	0	0	0	19	0	0	0	0	172	0
Isopoda (aquatic sowbugs)												
Asellus	0	0	0	0	0	38	287	153	0	19	0	19
Chironomidae (midges)												
Chironomus	19	38	19	0	19	19	38	96	0	0	19	19
other[1]	1,168	440	76	536	76	0	115	76	19	19	0	0

Table 7. (continued)

	Station											
	III-1		III-2		IV		VII		VIII		IX	
Trichoptera (caddisfly larvae)												
Phylocentropus	0	0	0	0	0	0	19	38	0	0	38	0
Oecetis	0	0	0	0	0	0	0	0	0	0	76	0
TOTAL	24,097	4,478	20,460	95,260	688	2,086	1,033	745	842	1,531	764	516

1 many are *Cryptochironomus*

Table 8. Benthic macroinvertebrates in Allouez Bay, Sept., 1974. Included are number/m^2 for each of three Ponar dredge samples and averages for each station. Locations of stations are shown in Fig. 1.

	A1			Average	A2			Average	IX			Average
Oligochaeta	0	0	0	0	0	0	0	0	38	19	38	32
Hirudinae (leeches)	0	0	0	0	19	0	0	6	0	0	0	0
Sphaeriidae (fingernail clams)	19	0	38	19	0	19	0	6	190	266	285	247
Amphipoda (scuds)												
<u>Gammarus</u>	0	0	0	0	0	0	0	0	133	19	0	51
Isopoda (aquatic sowbugs)												
<u>Asellus</u>	19	38	19	25	0	0	0	0	76	0	0	25
Diptera												
Chironomidae (midges)												
<u>Chironomus</u>	171	171	152	165	152	474	760	467	0	19	0	6
other	0	0	0	0	0	0	0	0	0	19	0	6
Phoridae	0	0	0	0	0	0	0	0	19	0	0	6
Trichoptera (caddisfly larvae)												
<u>Phlylocentropus</u>	0	0	0	0	0	19	0	6	0	0	0	0
<u>Oecetis</u>	0	0	0	0	0	0	0	0	0	19	0	6
TOTAL	209	209	209	209	171	532	760	488	456	342	342	380

Table 9. Benthic macroinvertebrates (number/m^2) in Lake Superior, vicinity of Duluth-Superior, fall,1973. Each column represents numbers in one Ponar dredge sample converted to number/m^2. See map (Fig. 1) for location of samples.

	Duluth - Old Dump Site							Superior - Old Dump Site										
	Sept. 14				Oct. 14			Sept. 14							Oct. 14			
				Av.			Av.							Av.				Av.
Pontoporeia	670	134	517	440	19	670	344	880	861	517	344	346	590		96	230	134	153
Chironomidae	38	0	19	19	306	1455	880	191	38	96	38	38	80		268	478	689	478
Oligochaeta	249	325	880	485	19	38	28	1416	2948	1474	1321	1110	1654		57	38	76	57
Sphaeriidae	0	0	0	0	19	0	10	0	0	0	0	0	0		0	0	0	0
TOTAL	957	459	1416	944	363	2163	1263	2487	3847	2087	1703	1494	2324		421	746	899	688

III. Laboratory Bioassay - Sublethal Effects of Mercury and Zinc on *Pontoporeia affinis*

A. Introduction

The Corps of Engineers requested that our laboratory bioassay utilize metals having EPA standards. We chose zinc and mercury, two metals which in excess amounts have been reported to be harmful to aquatic systems. (See Section I,C). Most studies on these metals in aquatic habitats have been concerned with the water column. Since sediment was of concern, we developed and conducted a sublethal bioassay for zinc and mercury in sediments on an important benthic animal from Lake Superior - *Pontoporeia affinis*. Both behavior and bioaccumulation experiments are included in our study.

B. Materials and Methods

1. Collection of Pontoporeia, sculpins, and sediments

Pontoporeia were collected in a small otter trawl which was modified by attaching a fish larvae net (circular aperture 500 microns, 1.5 m mouth diameter, 4 m long) for macroinvertebrates. This net was borrowed from James Selgeby of the U.S. Bureau of Sport Fisheries and Wildlife at Ashland, Wisconsin. The trawl was towed behind a 16-foot Boston whaler or a 40-foot commercial trawler. During mid-November and December, 1974 and January, 1975, bottom transects were made in the lake about 8 km from the Duluth-Superior harbor. Tows took place over 30-58 minute periods at depths of 30 to 45 m. Most hauls were made at night when more Pontoporeia were collected per haul. The trawl contents were placed in plastic bags containing Lake Superior water and battery-operated aerators. We experimented with collecting Pontoporeia with the Ponar dredge and separating them from the sediment by washing and sieving. This proved time consuming and damaging to the animals. All experiments included here were conducted with trawl-caught amphipods.

The Pontoporeia were transported to the University of Wisconsin's Trout Lake Biological Station and placed in holding trays that received a continuous flow (.08-.12 ml/min) of Trout Lake water. Temperatures were maintained between 6 and 8^{o}C. Each tray contained a silty-sand substrate collected from Lake Superior.

We estimated that 50% mortality in the holding tray occurred within the first week but the mortality rate was low thereafter. The initial loss of individuals may have been due to abrasiveness of the collecting technique, agitation from aerators, a change in atmospheric pressure (from

4 atm. at 35 m to 1 atm at surface), a change in bacterial flora, a different water source, or other factors. The amphipods were allowed to acclimate to laboratory conditions for two weeks before an experiment.

Slimy sculpins (Cottus cognatus) for the bioassay were collected on September 20, 1974 with the help of James H. Selgeby and staff of the U.S. Bureau of Sport Fisheries and Wildlife at Ashland, Wisconsin. Trawls were made in the Apostle Islands region off Cat and Michigan Islands at depths of 15 to 48 m. The fish were taken to the Trout Lake Biological Station and held in a Frigid Unit living stream facility at 4-6^{o}C.

Sediment for the bioassay was collected in gunny sacks off Minnesota Point in 10-16 m depths. All the sediment for the bioassay was collected at the same time and place.

2. Water Source for Bioassay

All experiments were conducted in water pumped from Trout Lake, Vilas County, Wisconsin, during the winter (November through February, 1974-75). Water quality parameters are outlined in Table 10. Temperatures were maintained at 4-5^{o}C.

3. Experimental Sediment

Concentrations of inorganic Hg++ (as HgCl) or inorganic Zn++ (as ZnCl) were added to 3.8 liters of lake water. This solution was added to a known quantity of sediment and mixed by hand once per day for three days. The treated sediment, prior to being added to the tanks, was thoroughly washed three times with lake water. Control sediment was

Table 10. Chemistry and Conductivity of Water
Note: Water for the bioassay came from Trout Lake, Vilas Co., Wisconsin. Dissolved oxygen and pH were measured on site at Trout Lake. All other parameters were contracted to the U.W. Extension Soils and Plant Analysis Lab. Representative values for some of the parameters in Lake Superior are included.

		December, 1974	February, 1975	L. Superior (Lawrie & Rahrer, 1972)
N	ppm	0.65	<.01	
P	"	3.92	<2.50	
K	"	13.7	<10.0	.5 - .6
Ca	"	14.2	11.4	12 - 13.2
Mg	"	3.14	2.23	2.7 - 2.8
Na	"	2.50	2.44	1.1 - 1.3
Al	"	0.386	<0.1	
Fe	"	0.291	0.240	.008 - .011
B	"	.0258	.0204	
Cu	"	.0273	.0804	.012
Zn	"	.0234	<0.01	.027
Mn	"	.0430	<0.02	.002
NO_3-N	"	.65	<.01	
Cl^-	"	1.0	1.0	1.3 - 1.9
Ba	"	.0336	<0.02	
Sr	"	.0434	.0124	
Cr	"	<.03	<.03	
NH_4-N	"	0.01	<.01	
PO_4-P	"	<0.01	.02	.004
SO_4-S	"	0.75	2.0	
Conductivity mhos x 10^{-5}/cm		10	10	9.5
Alkalinity ppm $CaCO_3$		35.27	39.30	46
Hardness (equiv., Ca & Mg only)		48.38	37.64	42.31[1]
D.O. (ppm)			16 at 5°C (super-saturated)	
pH			7.2	7.2 - 7.8

[1] Calculated from Adams (1972) data.

handled in the same way except that no metals were added. 1500 cm^3 of treated sediment was added to each of the six aquaria. After each experiment the sediment was removed. Tanks were soaked with 0.1 N HNO_3 for approximately 12 hours and rinsed thoroughly before re-using. Substrate samples for heavy metal analysis were withdrawn from the tanks before each experiment, 24 hours after the start, and at the conclusion of each experiment.

4. Experimental Apparatus

The bioassays were conducted in six molded fiberglass aquaria with plexiglass faces. Inside dimensions were 28 x 60 x 25 cm deep.

For behavioral observations tanks were arranged in two banks of three, facing a central observation blind. The darkened blind was made from masonite wall board supported by a wooden frame. The observer viewed the Pontoporeia through the glass face which could be covered by a light-tight panel between observations.

The experimental room was windowless and the door vents were covered. Test tanks were illuminated with 7.5 w frosted light bulbs providing 1.92 ft-c at the water surface. The photo period was 12 hours of light and 12 hours of darkness. Water temperatures were maintained at 4-5^{o}C.

5. Experimental Design

Details on the design of the experiments and periods of observation are outlined in Table 11. Sediment, added to the tanks in 1500 cm^3 aliquots, were allowed to settle for 24 hours. Pontoporeia were taken from

Table 11. Design of Experiments: Behavior Bioassay

Length of exposure of Pontoporeia	Two-day (48 hrs)	Five-day (120 hrs)
Sediment added to experimental tanks	Day 0	Day 0
Pontoporeia added (25 per tank)	Day 1, 0900 hrs.	Day 1, 0900 hrs.
Behavioral observations on Pontoporeia	Day 1, 2000 hrs. Day 2, 0800 and 2000 hrs. Day 3, 0800 hrs.	Day 1, 1900 hrs. Day 2, 1900 hrs. Day 3, 1900 hrs. Day 4, 1900 hrs. Day 5, 1900 hrs.
Number of tanks observed	3 (no behavioral observations in tanks selected for sculpin behavior)	6 on Days 1 to 4 3 on Day 5 (no behavioral observations in tanks with a sculpin)
Sculpin predation (one sculpin in half the tanks)	Day 2, 0900 - Day 3, 0900 hrs.	Day 5, 0900 - Day 6, 0900 hrs.
Sediments sieved, Pontoporeia counted	Day 3, 0900 hrs.	Day 6, 0900 hrs.
Number of days cleared on control sediment before analysis	3	3
Number of experiments	3 mercury 3 zinc	4 mercury 2 zinc
Dates of experiments	Nov. 22-Dec. 22, 1974	Jan. 6-Feb. 16, 1975

holding tanks and allocated at random to the six experimental tanks until each received 25 animals. Two tanks contained control sediment; two tanks contained one metal concentration; and two tanks contained another concentration of the same metal. For the first experiments Pontoporeia were exposed to the treated sediment for two days; in later tests, they were exposed to the sediment for five days. A sculpin was added to three of the six tanks (one sculpin/treatment) for the last 24 hours of each experiment. Sculpin of similar size and weight were selected and then allocated at random.

The behavior of Pontoporeia was measured by recording locomotor activity and numbers of active animals. Each tank was visited five times during an observation period. The order of tank visits was randomly selected for each period. Each visit proceeded as follows: a grid of vertical and horizontal lines, 4 cm apart, was placed in front of the viewing window. If the observations were at night a dim red light was turned on over the tanks. Five different observations were then made at each tank. Two observations were counts of the number of active Pontoporeia (as opposed to those burrowed and not visible)[1]; the other three observations were 30-second counts of lines crossed on the grid by an animal swimming and the number crossed while sinking[2]. The individual animal used for this measurement was randomly selected. The order of the five observations during each tank visit was

---

[1]The observer had 30 seconds for this count; if none were active in this time, a zero was recorded.

[2]Sinking was a behavior in which the amphipod would turn on its back and drop down with its upward-pointing appendages moving. This action often followed a pattern of swimming up to the surface, hitting the surface, then sinking to the bottom as described above.

also randomly determined. A lapse of 30 seconds was required between each of the five observations. One person recorded and timed observations; another person actually observed the animals. After visiting a tank, the observer turned off the red light (if it had been used) and proceeded to the next tank.

6. Analysis of Data

Median numbers of active Pontoporeia and median activity rates (lines crossed/30 sec) were calculated for each tank after each observation period. The effect of mercury or zinc was judged by the difference between treatment and control results. These differences were plotted in relation to the zero or control (for example, see Fig. 20). The plots show median, range and 90% confidence limits. The latter was calculated according to Conover (1971).

If a treatment had no effect on Pontoporeia, we would expect the treatment minus control values should fall evenly above and below zero. We used a one-sample X^2 test and $p \leq 0.05$ (Siegel, 1956) to determine the statistical significance of treatments.

7. Analysis for Metal Content

Pontoporeia were placed on control sediment after each experiment to allow replacement of treated-sediment particles in their alimentary tract with "clean" particles. After 72 hours on these sediments, they were frozen and transported to Madison for chemical analysis.

The three day period for cleaning of the alimentary tract was determined on the basis of an early experiment in which four samples of Pontoporeia were analyzed for scandium. Scandium is a trace element associated with soils but not with organisms and is therefore a good indicator of the

presence of sediment in the alimentary tract. The first sample of *Pontoporeia*, quick-frozen after field collection, contained .47±.01 ppm scandium. The second sample of *Pontoporeia*, after several days exposure on Lake Superior sediments used in the experiments, had .2-.6 ppm scandium. The third sample of *Pontoporeia* had been placed in Trout Lake water for 48 hours with no sediment present. These animals averaged .09 ± .01 ppm scandium. The fourth sample of *Pontoporeia*, placed on sea sand for 48 hours, averaged .07 ± .01 ppm of scandium. Therefore, we concluded that most of the initial sediment in the tract was eliminated in 48 hours. Whole *Pontoporeia* were analyzed by neutron activation analysis, as described in Volume 5. We do not know how much, if any, damage to tissue structure occurred during freezing of the samples. Neither do we know if this could result in a loss of trace elements from the *Pontoporeia* samples. Samples of bioassay sediments were analyzed by atomic absorption as in Volume 5.

8. Accumulation Experiments

Pontoporeia were exposed to mercury and zinc sediments for two weeks. The experiments are outlined in Table 12. Individuals were removed before the experiment, and at 1, 2, 3, 4, 5, 6, 10 and 14 days. These animals were placed on control sediment for three days before they were frozen for analysis, as described previously. Sediments were prepared in the same manner as they were for the behavior bioassay. Water temperature was 4-4.5°C.

Table 12. Design of experiments: Two-week accumulation

All Pontoporeia were placed on control sediment for three days before freezing for analysis.

Male Pontoporeia were in their last instar and were dying faster than the females which were still carrying eggs and young.

	Mercury females	Mercury males	Zinc females	Zinc males
1. Pontoporeia sample for baseline level	30	30	30	0
2. Pontoporeia placed on experimental sediment	350	350	400	217
Days 1-14				
Pontoporeia samples removed from experimental tray				
Day 1	30	30	30	30
2	30	30	30	20
3	30	30	30	13
4	30	30	30	0
5	30	30	30	0
6	30	30	30	0
10	30	1	30	0
14	30	0	20	0
Sediment samples taken	Days 1, 7, 14		Days 0, 7, 14	
Dates of experiment	Jan. 28 - Feb. 11		Feb. 9 - Feb. 23	

C. Results

1. Behavioral Experiments

a. Mercury Experiments

Pontoporeia were exposed to .65-1.15 ppm Hg in the bioassay sediments in the two day experiments and to 2.15-3.35 ppm Hg in the sediments in the five-day experiments. Survival of Pontoporeia on mercury-treated sediments was similar to survival of Pontoporeia on control sediments in 12 of 14 tanks (Table 13). In the first of the exceptions (Expt. 8) some amphipods may have escaped through a hole in the drainpipe. In the other exception (Expt. 14), 19 animals were found dead in one tank. The cause was unknown. However, we do consider our experimental exposures to mercury to be sublethal on a short-term basis.

In the five-day experiments the number of active Pontoporeia and their rate of activity on mercury-treated sediments were statistically lower than the controls (at $p = 0.02$, x^2 test) when data from all five nights of observation were combined (Figure 20). During the first two nights of observation only one of the three activity measures was statistically different from controls (Figure 21). The combined number of active Pontoporeia on third, fourth and fifth nights in the experimental tanks was statistically below the number of active animal controls at a $p = 0.001$, x^2 test (Figure 22). The rates of activity also tended to be depressed. However, these were not statistically lower at a chi square probability greater than 70-80%.

The two-day experiments tended to have fewer active animals and decreased activity rates; medians and 90% confidence limits were well below the controls (Figure 23). These differences were not statistically significant ($p > 0.20$, x^2 test).

Pontoporeia in the behavioral experiments increased their body burden of mercury by almost 100 times in the two-day experiments and by 100 to 1000 times in the five-day experiments (Figure 24).

Table 13. Mercury: Survival of Pontoporeia in experimental tanks not subject to fish predation.

Experiment	Sediment Mercury Concentrations ppm Beginning	End	Average		Number of Live Pontoporeia Beginning	End
Two-day exposure						
7 (Pont. immature, males and females indistinguishable)	.05	.05	.05	(control)	25	23
	0.7	0.6	.65		25	23
	0.9	1.0	.95		25	24
8[1] "	.05	.05	.05	(control)	25	19
	0.7	0.6	.65		25	23
	1.1	1.2	1.15		25	7
9 "	.05	.05	.05	(control)	25	23
	0.6	0.7	.65		25	22
	0.9	--	.90		25	19
Five-day exposure						
13 (becoming mature; immature selected where possible)	.01	.01	.01	(control)	25	23
	1.6	2.95	2.28		25	19
	2.5	2.5	2.50		25	25
14[1] "	.01	.01	.01	(control)	25	22
	1.75	2.55	2.15		25	15
	2.4	2.35	2.38		25	5
17 (all mature; half male, half female)	.01	.01	.01	(control)	25	17
	2.55	1.9	2.23		25	13
	2.95	2.88	2.88		25	17
18 (all female in four tanks; half female in two)	.01	.01	.01	(control)	25	23
	--	2.35	2.35		25	16
	--	3.35	3.35		25	18

[1] See text page 75.

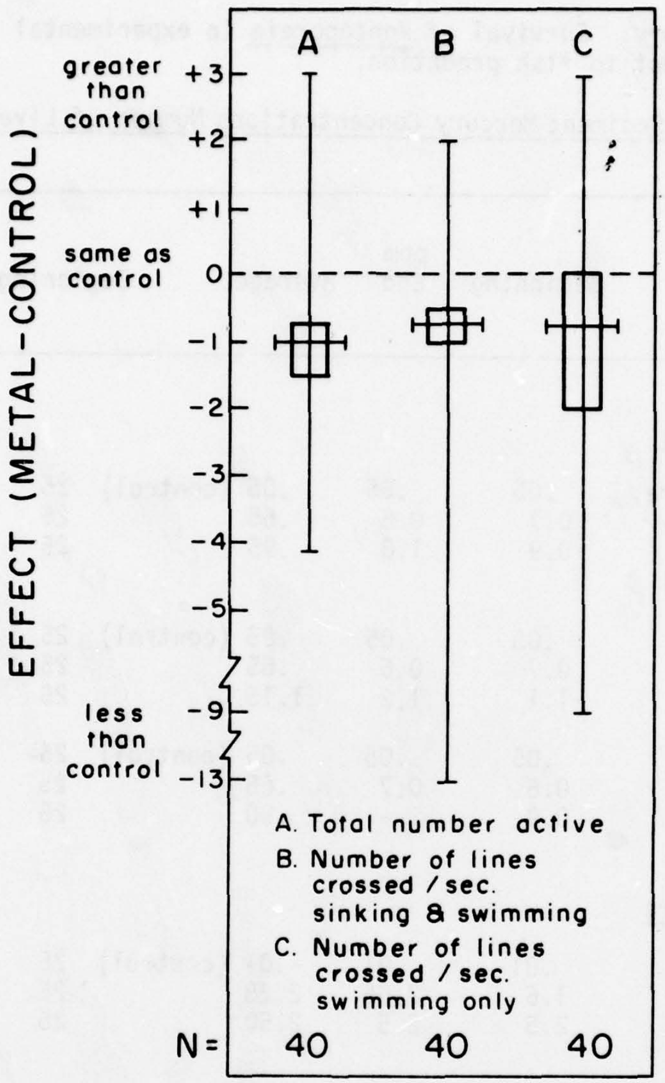


Fig. 20. Pontoporeia activity--five-day experiments with mercury; five nights of observation.

Note: Medians, 90% confidence limits, and ranges of Pontoporeia activity on mercury-treated sediments (2.15-3.35 ppm Hg) expressed as a difference from control sediments (.01 ppm Hg). Data from all five nights of observation were combined. Differences are significant at p=.02, x^2 test. Actual medians for controls were 3-9.5 (total # active), 11-17 (# lines crossed/30 sec swimming and sinking), and 7-17 (# lines crossed/30 sec swimming only).

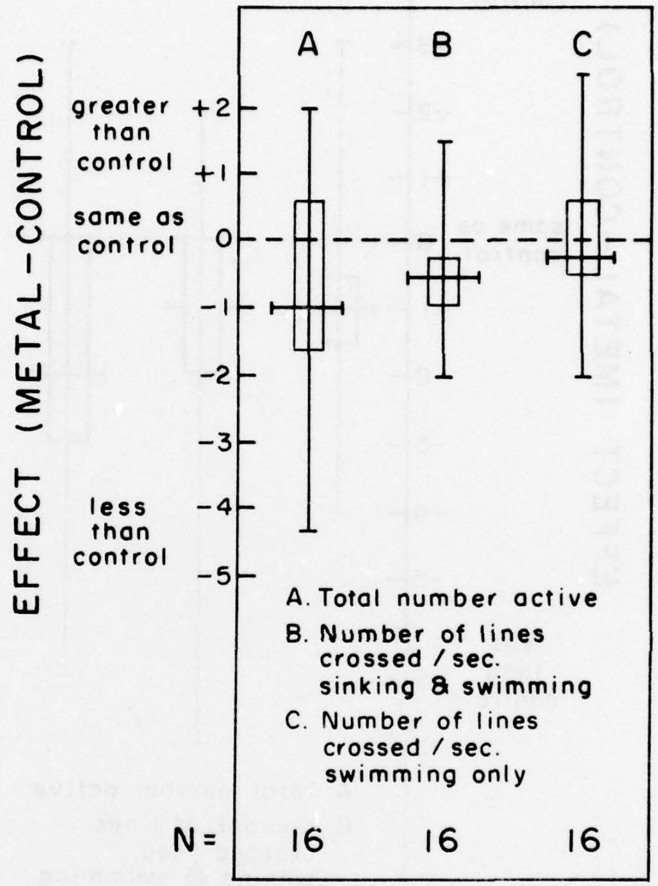


Fig. 21. Pontoporeia activity--five-day experiments with mercury; first two nights of observation.

Note: Medians, 90% confidence limits, and ranges of Pontoporeia activity in mercury-treated sediments (2.15-3.35 ppm Hg) expressed as a difference from control sediments (.01 ppm Hg). Data from the first two nights of observation were combined. The # lines crossed/30 sec swimming and sinking was significantly different at $p = .05$, x^2 test. Actual medians for controls were 4-9.5 (total # active animals), 12-15 (# lines crossed/30 sec swimming and sinking), and 9-14 (# lines crossed/30 sec swimming only).

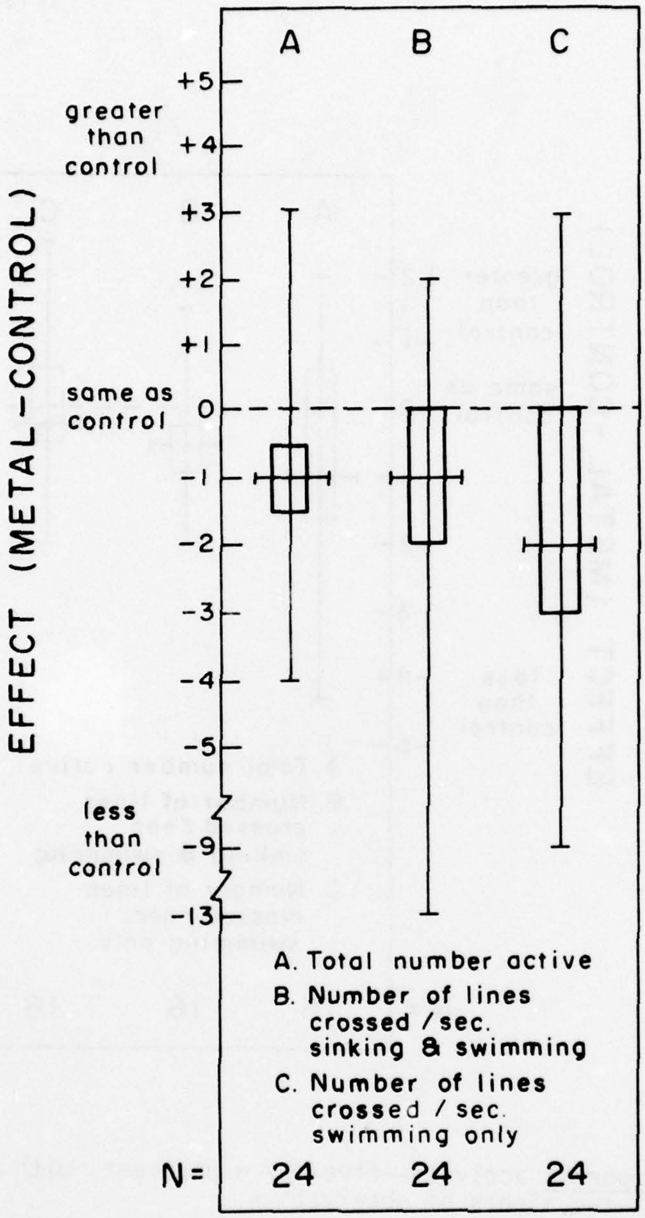


Fig. 22. Pontoporeia activity--five-day experiments with mercury; third, fourth, and fifth nights of observation.

Note: Medians, 90% confidence limits, and ranges of Pontoporeia activity on mercury-treated sediments (2.15-3.35 ppm Hg) expressed as a difference from control sediments (.01 ppm Hg). Data from third, fourth and fifth nights of observation were combined. The total number of active animals was significantly lower than controls at p=.001, x^2 test. Actual medians for controls were 3-8 (total # active), 11-17 (# lines crossed/30 sec swimming and sinking), and 7-17 (# lines crossed/30 sec swimming only).

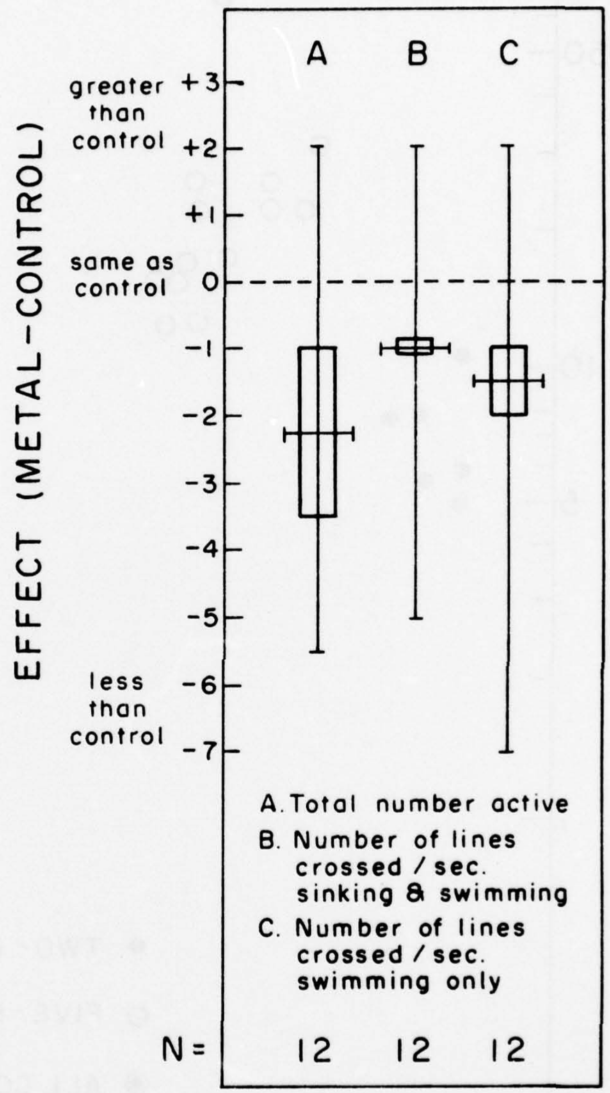


Fig. 23. Pontoporeia activity--two day experiments with mercury; two nights of observation.

Note: Medians, 90% confidence limits, and ranges of Pontoporeia activity in mercury-treated sediments (.65-1.15 ppm Hg) expressed as a difference from sediments (.05 ppm Hg). Data from two nights of observation were combined. Actual medians for controls were 4-11 (total # active), 11-17 (# lines crossed/30 sec swimming and sinking), and 7-17 (# lines crossed/30 sec swimming only).

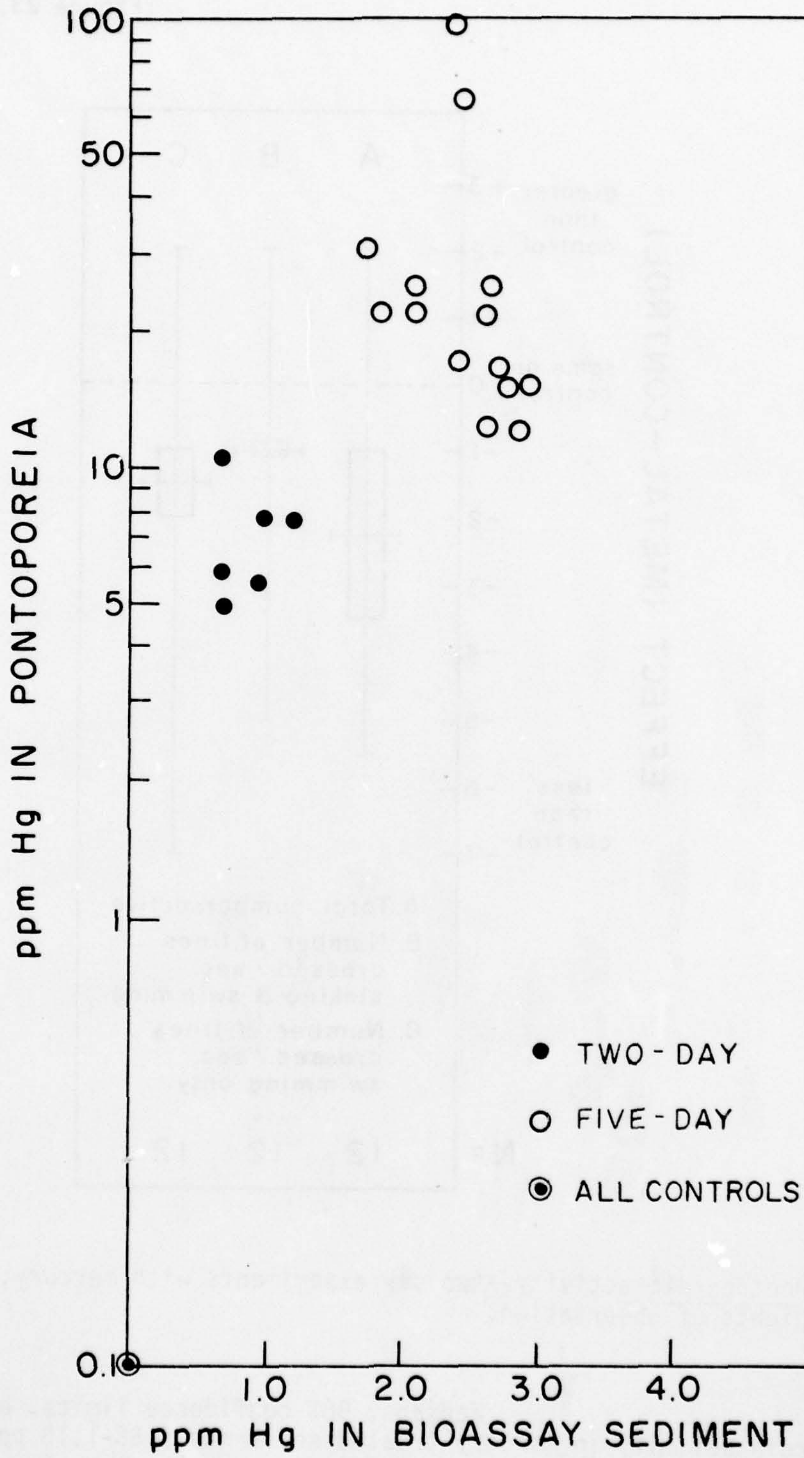


Fig. 24. Concentration of mercury in whole Pontoporeia in the two-day and five-day experiments. After each experiment the amphipods were held on control sediment for three days before freezing to clear their alimentary tracts of treated sediment.

b. Zinc Experiments

Zinc levels in the bioassay sediments (58.5-123.5 ppm Zn) were below or within the present EPA guidelines for moderately polluted sediment (90-200 ppm Zn). Control sediment concentrations ranged from 16-26 ppm Zn. Survival of Pontoporeia in zinc-treated sediments was not different than survival in controls in all but one experiment (Table 14). We considered the experimental zinc levels to be sublethal to Pontoporeia in these experiments. In the one exception (Experiment 12), most controls died within 24 hours. Activity in all tanks was low during Experiment 12, and we suspect that the length of time the animals were held in the laboratory and/or some water quality problem interfered. Thus, data are presented below with and without Experiment 12.

There were no tendencies or significant differences in tanks with zinc-treated sediments versus controls in the two-day experiments (Figure 28) with or without results from Experiment 12.

In the five-day experiments, the number of active Pontoporeia in the zinc-treated sediments was not different from the number of active animals in controls (Figures 25, 26, 27). However, the rate of activity was significantly different from the controls ($p = .001$, x^2 test) for the third, fourth and fifth nights of observation and for all five nights combined (Figure 26, 27). This was not true for the first two nights of the five-day experiments (Figure 25).

The body burdens of zinc in Pontoporeia were slightly elevated over

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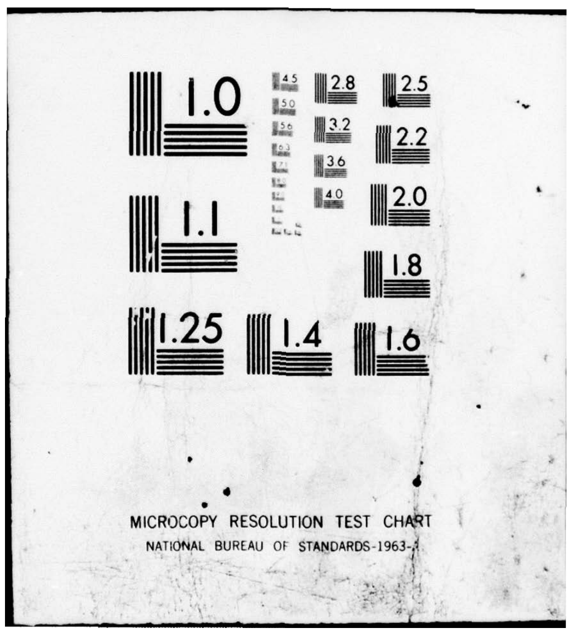
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controls in the two-day and five-day studies (Figure 29). Control animals contained 65 to 79 ppm Zn and treated animals had 89 to 150 ppm Zn after the two-day experiments. Control and treated Pontoporeia had 83 to 99 and 92 to 146 ppm Zn, respectively, after the five-day experiments.

Table 14: Zinc: Survival of Pontoporeia in experimental tanks not subject to fish predation.

Experiment	Sediment Zinc Concentrations ppm Beginning	End	Average	Number of Live Pontoporeia Beginning	End
Three-day exposure					
10 (Pont. immature, males and females indestinguishable)	19	33	26 (controls)	25	23
	71	65	68	25	22
	97	102	99.5	25	25
11 "	8	18	13 (controls)	25	22
	71	75	73	25	21
	95	80	87.5	25	23
12 "	--	19	19 (controls)	25	4
	--	92	92	25	23
	--	86	86	25	20
Five-day exposure					
15 (increasing productive maturity	15	17	16 (controls)	25	12
	77	50	58.5	25	18
	140	103	121.5		
16 "	20	12	16 (controls)	25	18
	67	63	65	25	19
	120	127	123.5	25	12

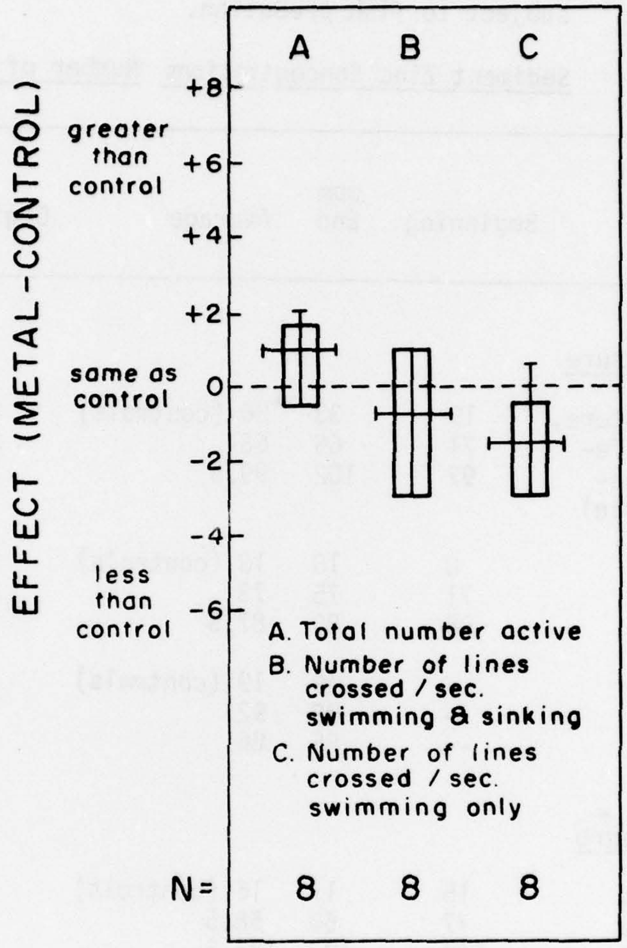


Fig. 25. Pontoporeia activity--five-day experiments with zinc; first two nights of observation.

Note: Medians, 90% confidence levels, and ranges of Pontoporeia activity in zinc-treated sediments (58.5-123.5 ppm Zn) vs. control sediments (16 ppm Zn). Data are from the first two nights of observation only. Actual medians for controls were 6-9.5 (total # active), 10-14 (# lines crossed/30 sec. swimming and sinking) and 7-13 (# lines crossed/30 sec swimming only).

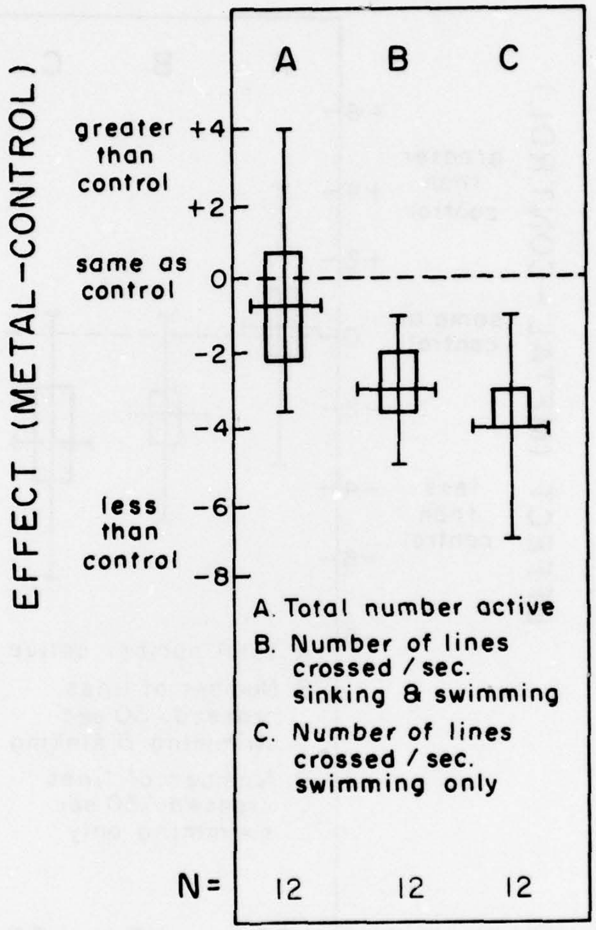


Fig. 26. Pontoporeia activity--five-day experiments with zinc; third fourth and fifth nights of observation.

Note: Medians, 90% confidence levels, and ranges of Pontoporeia activity in zinc-treated sediments (58.5-123.5 ppm Zn) vs. control sediments (16 ppm Zn). Differences from controls were significant at p<.001, x^2 test for # lines crossed/30 sec swimming and sinking and for swimming only. Data from the third, fourth and fifth nights of observation were included. Actual medians for controls were 5.5-9 (total # active), 14-18 (# lines crossed/30 sec swimming and sinking), and 11-18 (# lines crossed/30 sec swimming only).

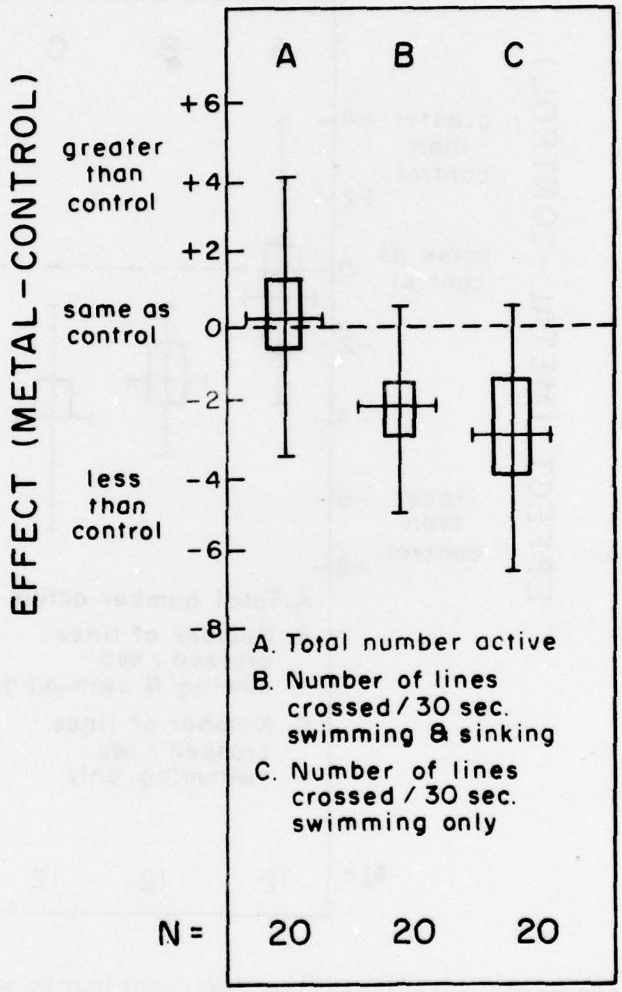


Fig. 27. Pontoporeia activity--five-day experiments with zinc; five nights of observation.

Note: Medians, 90% confidence levels, and ranges of Pontoporeia activity in zinc-treated sediments (58.5-123.5 ppm Zn) vs. control sediments (16 ppm Zn). Data from all five nights of observation were combined. Differences from controls were significant at $p<.001$, x^2 test for # lines crossed/30 sec swimming and sinking and for swimmers only. Actual medians for controls were 5.5-9 (total # active), 10-18 (# lines crossed swimming and sinking), and 7-18 (# lines crossed swimming only).

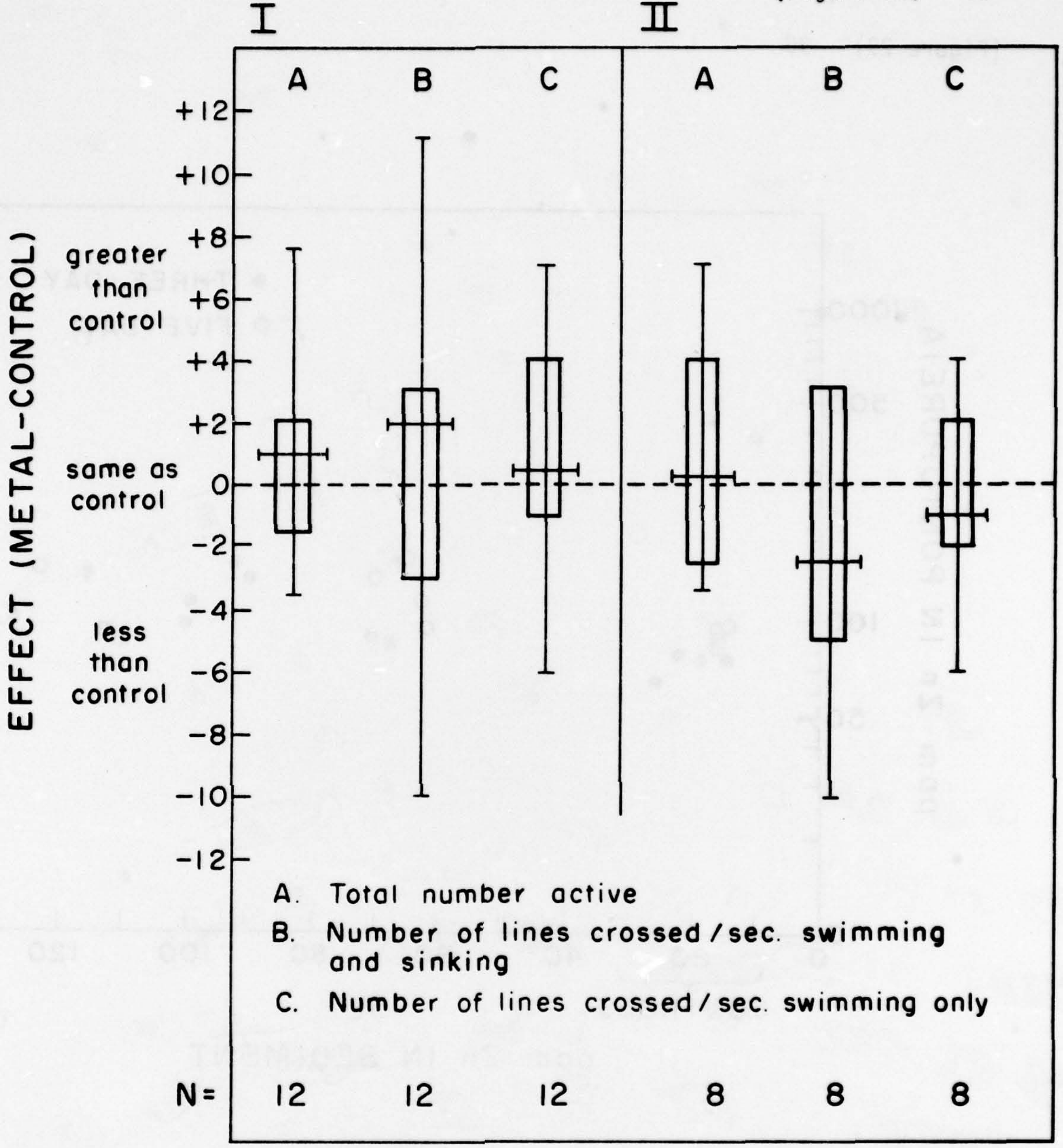


Fig. 28. Pontoporeia activity--two-day experiments with zinc; two nights of observation.

Note: Medians, 90% confidence levels and ranges of Pontoporeia activity in zinc-treated sediments (68-99.5 ppm Zn) vs. control sediments (13-26 ppm Zn). Data from both nights of observation are combined and shown with (I) and without (II) Experiment 12. Actual medians for controls were 0-3.5 and 2-3.5 (total # active, Expt. 12 included and excluded, respectively), 0-18 and 7-18 (# lines crossed/ 30 sec swimming and sinking, Expt. 12 included and excluded, respectively) and 0-15 and 3-15 (# lines crossed/30 sec swimming only, Expt. 12, included and excluded, respectively).

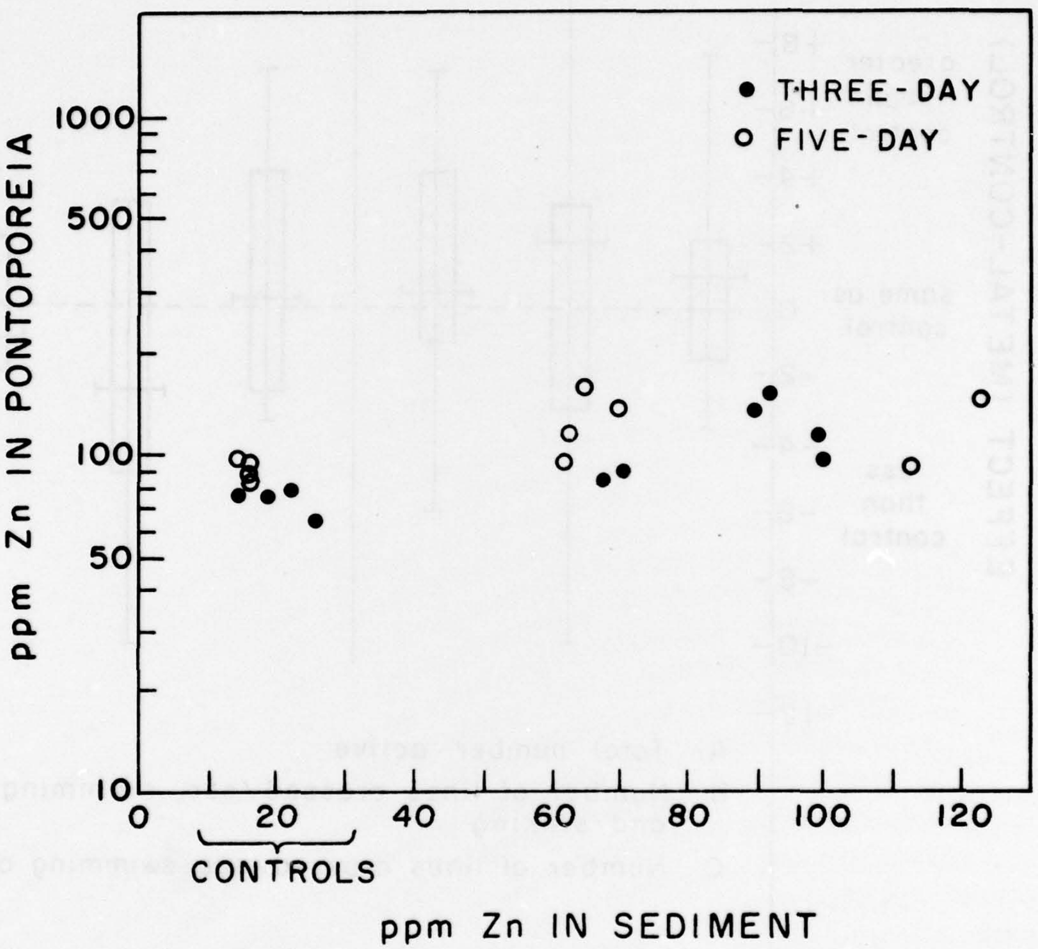


Fig. 29. Concentration of zinc in whole Pontoporeia in two-day and five-day experiments. After each experiment, amphipods were held on control sediment for three days before freezing to clear their alimentary tracts of treated sediment.

c. Predation Experiments

Mercury had no discernible effect on the availability of Pontoporeia to sculpin predation in our experiments. This was true for two and five day data sets combined (Figure 30). It was also true for the two-day and five-day experiments considered separately.

In the five-day experiments more Pontoporeia on zinc-contaminated sediments, were eaten by sculpin than were Pontoporeia on control sediments; the sample size was only four sculpin. Zinc did not affect predation in the two-day experiment.

When two and five-day experiments were combined to increase the sample size to ten fish, more Pontoporeia were consumed on zinc-contaminated than on control sediments (Figure 30).

The fish did not consume enough mercury or zinc in 24 hours to attain a detectable metal level in their tissues.

2. Accumulation Experiments

Male and female Pontoporeia concentrated similar quantities of mercury in the first week of the two-week uptake study on 3.5-4.0 ppm mercury-enriched sediment (Figure 31). Both sexes had background whole-body levels of 0.1 ppm Hg at the outset and increased over one-hundred fold within the first week. After that time no males were available. The rate of mercury uptake in the females began to level off in the second week, with whole body concentrations reaching 40 ppm.

Accumulation of zinc was similar for males and females, but living males were absent after four days (Figure 32). Whole-body levels of zinc doubled in females within two weeks. The females at the beginning of the experiment had 93 ± 6 ppm zinc. After 14 days, the females had 185 ± 10 ppm zinc.

The lack of overlap shows that zinc enrichment of female Pontoporeia occurred. There were small decreases in sediment levels of mercury and zinc in the experimental tanks through the two-week period. Sediment concentrations of mercury and zinc were determined at the beginning, middle and end of the experiments. Results are graphed in Fig. 31, and Fig. 32. The actual values[1] are included below:

Sediment concentration (ppm)

Zinc		Mercury	
Day 0	127 ± 12	Day 1	4.0 ± 0.4
Day 7	117 ± 6	Day 7	3.8 ± 0.4
Day 14	99 ± 10	Day 14	3.5 ± 0.4

Even though the 95% confidence limits overlap, there is evidence for a decline in zinc over the two-week period. We estimated the amount of zinc lost to the water column from the experimental sediments from Day 0 to Day 14. In considering the constant exchange of water in the tank and assuming a gradual release of zinc from sediments, we estimate that the maximum level of zinc in the water column at any one time would have been .05 ppm. In examining the confidence limits for the two-week mercury experiment, the decline in mercury in the sediments from Day 1 to Day 14 was probably not significant. However, we made the same type of estimate as above for mercury in the water column. The amount contributed to the water column by the sediments could have been 9.9×10^{-10} ppm mercury at any one time in our flow-through system. This value is well below the detectable limits for neutron activation and below a level with any known biological effect.

[1]Concentrations given above represent actual values 95% confidence limits (± 2 standard deviations). The ± 2S.D. is based on counting statistics for the sample, not on replicate samples of Pontoporeia.

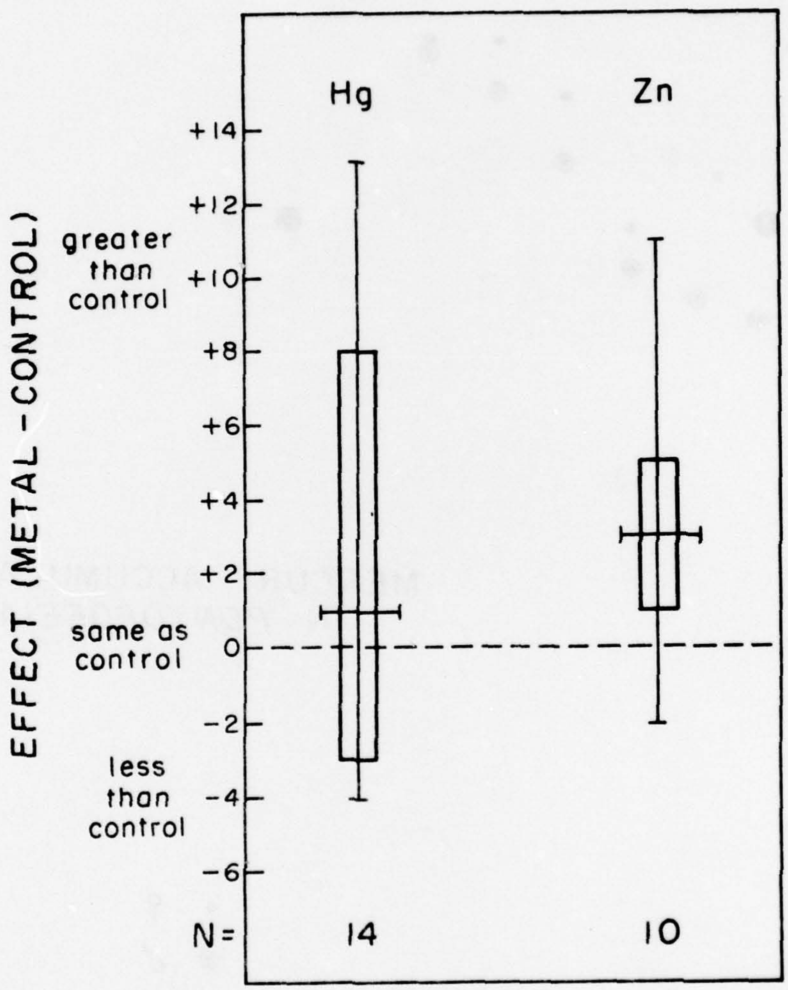


Fig. 30. Predation (# of Pontoporeia eaten/24 h) by sculpin on mercury-treated sediments (0.6-2.8 ppm Hg) vs. control sediments (<.05 ppm Hg) and on zinc-treated sediments (58.5-123.5 ppm Zn) vs. control sediments (14.5-22 ppm Zn). Medians and ranges are shown; 90% confidence limits are included where sample size permits. Actual medians for controls were 5-19 for Hg and 1-19 for Zn.

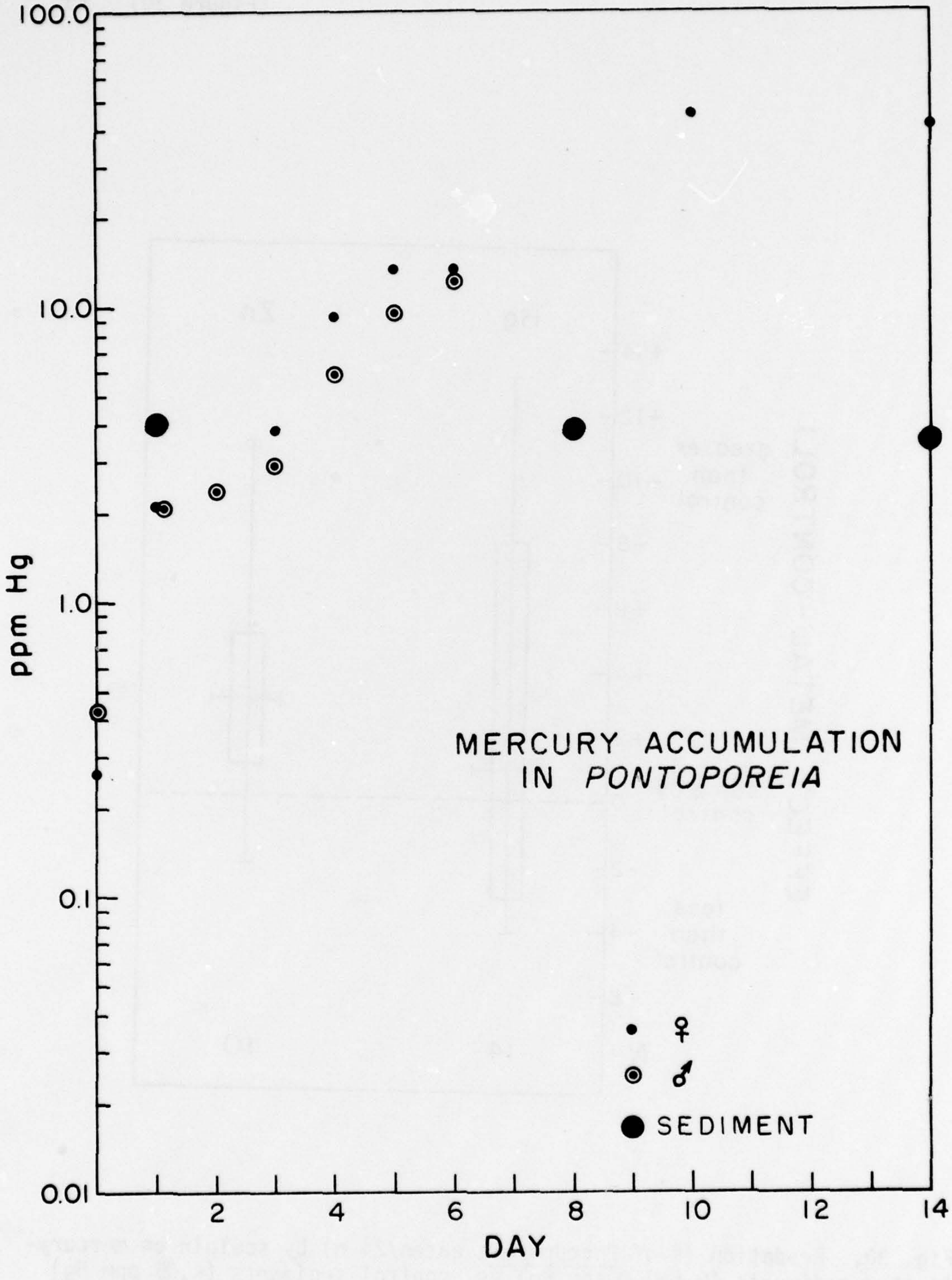


Fig. 31. Concentrations of mercury in whole Pontoporeia over two weeks' exposure to mercury-treated sediments. After each experiment, amphipods were held on control sediment for three days before freezing, to clear their alimentary tracts of treated sediment.

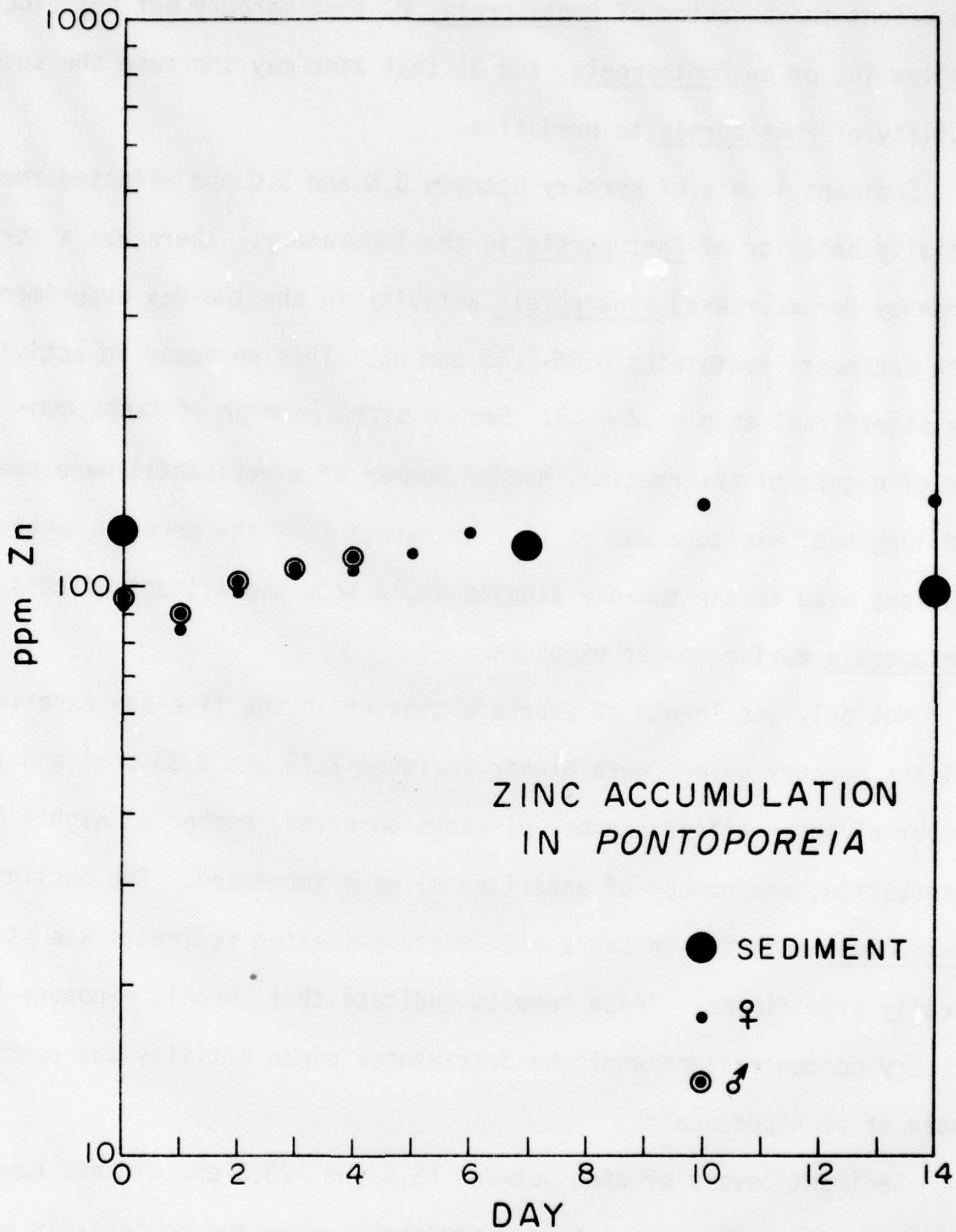


Fig. 32. Concentration of zinc in whole Pontoporeia over two weeks' exposure to zinc-treated sediments. After each experiment, amphipods were held on control sediment for three days before freezing, to clear their alimentary tracts of treated sediment.

D. Discussion

The bioassay experiments showed 1) that mercury and zinc in sediments can affect the behavior of Pontoporeia, 2) that mercury but not zinc multiplies in, or on Pontoproeia, and 3) that zinc may increase the susceptability of Pontoporeia to predation.

Sediment levels of mercury between 0.6 and 3.0 ppm affected the activity behavior of Pontoporeia in the laboratory. There was a strong tendency for decreased Pontoporeia activity in the two-day experiments with sediments containing 0.65-1.15 ppm Hg. This decrease in activity was significant at p = .2 - .3. Sample sizes (number of tanks, number of nights of observation, and/or number of experiments) were small and length of exposure was short. We expect that the mercury concentrations used in the two-day studies would show significant effects on Pontoporeia during longer exposures.

Not only was length of exposure greater in the five-day experiments, but the mercury values were higher (between 2.15 and 3.35 ppm) and the number of observations (number of tanks observed, number of nights of observation, and number of experiments) were increased. The decline in Pontoporeia activity in tanks with mercury-treated sediments was statistically significant. These results indicate that chronic exposure to these mercury concentrations would be detrimental since activity was used as an index of amphipod health.

Sediment levels of zinc between 58.5 and 123.5 ppm did not cause a change in the numbers of active Pontoporeia, compared to controls but their lower rate of activity was statistically significant in the five-day experiments. This was not the case in the two-day experiments.

Availability of Pontoporeia to predation by slimy sculpin (Cottus cognatus) was not affected by mercury in the sediments at the above concentrations. (.65-3.35 ppm). While there is evidence that zinc increased the sus-

ceptibility of Pontoporeia to predation, the results were not strong because of the small number of sculpin used. Single sculpin were used in each experiment to avoid the effects of competition, which might produce erratic results. The results were based on only 21 fish for mercury and 15 fish for zinc. The equivalent number of Pontoporeia tested in the behavior experiments were 1050 for mercury and 750 for zinc. Our intention was to measure susceptibility of Pontoporeia to predation. The 24-hour exposure of sculpin was not long enough to measure direct effect on the fish. However, Pontoporeia are the major food source of slimy sculpins in Lake Superior (Anderson and Smith, 1971; Selgeby, personal communication), and a steady diet of contaminated amphipods could affect the fish.

A potentially important difference between the two-day and the five-day exposures was the age and size of the Pontoporeia. Immature animals were used in the two-day studies; the Pontoporeia were collected and used in November and December. Males and females were indistinguishable. Pontoporeia for the five-day studies were collected in January and used in January and February. By early February great numbers were reproductively mature. Females were carrying eggs and young; males had undergone their last molt and, according to the literature, should no longer be feeding (Henson, et al., 1973). Males die after this last molt. This explains the lower survival rates in the later experiments (Table 13 and 14). It is not known whether or not mature Pontoporeia are more or less susceptible to stress than immature instars.

Zinc did not magnify in the bodies of Pontoporeia in our experiments as did mercury; this is consistent with the literature. However, we did observe an enriched zinc level in the amphipods on zinc-treated sediments.

This increase was greatest in the two-week exposure. There was no difference in accumulation between the two- and five-day experiments.

Uptake of mercury by Pontoporeia in the behavioral experiments and the two-week accumulation experiment was dramatic. We do not know the form of this mercury nor the extent to which the mercury may have bound to the exoskeleton. When Pontoporeia are consumed by fish, the exoskeleton is broken down into small pieces during digestion and these pieces are exposed to digestive enzymes whether or not the exoskeleton is totally digested.

Some of the food ingested by the Pontoporeia was in the Lake Superior sediment and some may have been provided by organisms and organic matter in the Trout Lake water. We do not know if any mercury was taken up by the Trout Lake organisms and then passed to the Pontoporeia.

The technique of washing the bioassay sediment was intended to remove any unbound zinc or mercury from the mixture. However, much of the fine sediment particles also washed out in the process. Higher concentrations of metals are associated with the fine sediment fractions (Volume 5). Pontoporeia probably ingest these particles (Marzolf, 1965a). Since the amount of fine sediment was reduced in the laboratory experiments, the route of metal uptake may have differed from Pontoporeia feeding in nature.

The question of the form of mercury in the laboratory-treated sediment (added inorganically as the chloride) and its form when measured in whole Pontoporeia cannot be answered. We do not know how much mercury, if any, was methylated in the laboratory sediments or in the laboratory organisms. We know that there was more soluble zinc in our bioassay sediments than in nature (Volume 5). We examined the mercury and zinc separately; the synergistic effects were not measured. We have no conclusive

evidence of synergisms at present, but we did some preliminary experiments in which a combination of 0.6 ppm Hg and 30 ppm Zn caused high mortalities of Pontoporeia in ten days. However, difficulty with temperature controls (6.8-13.3^{o} C range) indicate that temperature stress may have been an additional or primary factor.

Two lines of evidence indicate that the bioassay was a sediment bioassay and not a set of experiments utilizing soluble zinc or mercury in water to affect the test animals. First; an analysis of interstitial water in bioassay sediment used for two and five day mercury experiments was done. The amount of mercury present was below the limit of detection: .01 ppb. Second; the possible concentrations of zinc and mercury in the water, due to solubilizing from the sediments, were very low. Maximum concentrations of zinc and mercury in the water column at any time during the two week accumulation experiments were estimated to be .05 ppm zinc and 9.9×10^{-10} ppm mercury. These are the concentrations attributable to transfer from the sediments to the water column. Concentrations of mercury and zinc in sediments were determined at the beginning and end of the two and five day experiments. Estimates for metals contributed to the water column during these experiments would be the same or lower than for the two week experiment described above because: 1) zinc values in the sediments were in the same range as the longer, two-week experiment and mercury concentrations were lower than the values measured in the sediments of the longer tests, and 2) the flow rate of water in the experimental tanks was faster for these shorter experiments. We conclude that the bioassay experiments were sediment bioassays. The small amounts of metal contributed to the water column by the contaminated sediments are insignificant for mercury and very low for zinc.

IV. The Effects of Offshore Dredged Material Disposal on Shorebirds (Scolopaidae and Charadriidae) and Gulls and Terns (Laridae)

A. Introduction

The shores of the Great Lakes are used as migration stops for shorebirds (Scolopacidae and Charadriidae) and for gulls and terns (Laridae). The shores are used as resting, sleeping, and feeding areas. Migration creates a heavy physical and energetic strain on migrating birds. Periodic stopover points to rest and feed are necessary if these birds hope to successfully reach either their breeding or wintering grounds. It is also important that birds have stopover areas along their migration routes where they can sit out bad weather, which they frequently encounter during the spring and fall migration periods.

The alterations of physical and biological components of the migrating bird's environment could show up as any one of the following:

a) no effect, bird usage of an area stays the same

b) changes in abundance of species

c) elimination of particular species

d) addition of particular species

e) shift in micro-habitat usage within area

f) shift from one foraging behavior pattern to another foraging pattern

g) the lowering or raising of the foraging efficiency

The purpose of this study was 1) to survey the shorebird, gull and tern populations in and near the Duluth-Superior harbor and at the northwest shore of the Keweenaw Peninsula; 2) to evaluate the possibility of utilizing the above characteristics (a through g) to assess the impact of offshore dredged material dumping on migratory birds.

B. Previous Work

If dredged material dumping alters water or sediment quality and if the change in water or sediment quality has an effect on the aquatic invertebrates, the fish and birds that feed upon aquatic invertebrates or the birds that feed upon fish might also be affected. The food web relationships of Lake Superior aquatic organisms are discussed at length on pages 6 to 9 of this volume. Potential concentration of heavy metals in the aquatic food web is reviewed on pages 15 to 19. We consider below the two groups of migrating birds observed in this study: the shorebirds (Scolopacidae and Charadriidae) and the gulls and terns (Laridae).

1. Shorebirds

Shorebirds feed mainly on invertebrates which they find in the water, on the bottom of bodies of water, buried in the beach substrate and on top of the beach substrate (Bent, 1927, 1929; Brooks, 1967). There have not been, to our knowledge, qualitative or quantitative studies on the invertebrate communities of Lake Superior beaches.

Brooks (1967) found that each species of shorebird that he studied ate a variety of different prey species, but one particular prey species made up a large proportion of the total.

Different species of shorebirds behave differently when foraging. Thomas and Dartnall (1971) and Bengtson and Svensson (1968) found differences in the prey of species of shorebirds with different foraging behaviors. Baker and Baker (1973) divided shorebird foraging behavior into eight different categories and found that each category defined a statistically different way of exploiting the food base. Baker and Baker (1973) found that each species forages in one or a few characteristic

and predictable patterns. The diversity of a species' foraging patterns was directly correlated with the diversity of the prey types it ate.

Each species of shorebird forages on only particular portions of the available beach substrate. Baker and Baker (1973) and Recher (1966) found each species has a characteristic portion of the total substrate to which it will confine its foraging.

2. Gulls and Terns

Gulls are general feeders eating a wide range of food types (such as fish, insects, carrion, vegetable matter, and garbage). Gulls on Lake Superior forage heavily in man-altered or man-created areas (Harris and Matteson, 1975). Measuring the impact of offshore dredge spoil dumping on gulls is a difficult task because of their high usage of man-altered areas.

Terns in the Duluth-Superior harbor area feed primarily on small fish which they catch either in lake Superior or in the bays of the harbor (Harris and Matteson, 1975).

Ring-billed Gulls and Common Terns nest in the Duluth-Superior harbor in the summer (Harris and Matteson, 1975). Both of these species eat fish and feed fish to their young. Concentration of heavy metals by fish is documented in pages 15 to 19 of this volume. Concentration of mercury in fish-eating birds near sites of industrial contamination has been documented (Fimreite et al., 1971). It has also been documented that chemical contaminants in the environment (including mercury and various pesticide residues) have had negative effects on reproductive success in gulls and terns (Ludwig and Tomoff, 1966; Keith, 1966; Anderson, 1970; Switzer, et al., 1971; Hays and Risebrough, 1972; Faber and Hickey,

1973; and Ryder, 1974). Concentrations of these contaminants in Lake Superior gulls were lower than in gulls with reproductive failures in other localities (Anderson, 1970; Ryder, 1974). Considering this data and their own observation on Lake Superior gulls and terns, Harris and Matteson (1975) feel that chemical contamination is not at present an important detriment to gull and tern reproduction on Lake Superior.

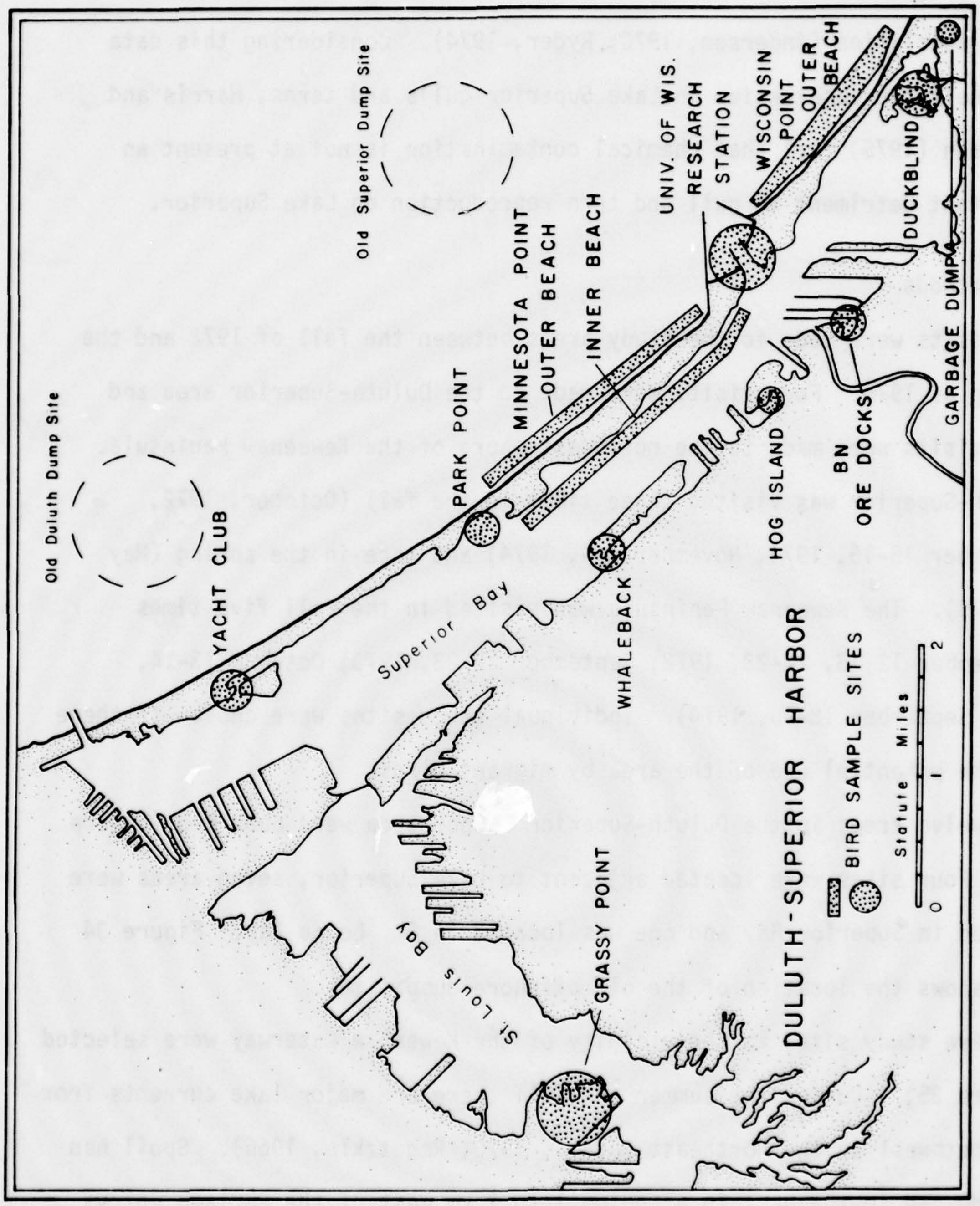
C. Methods

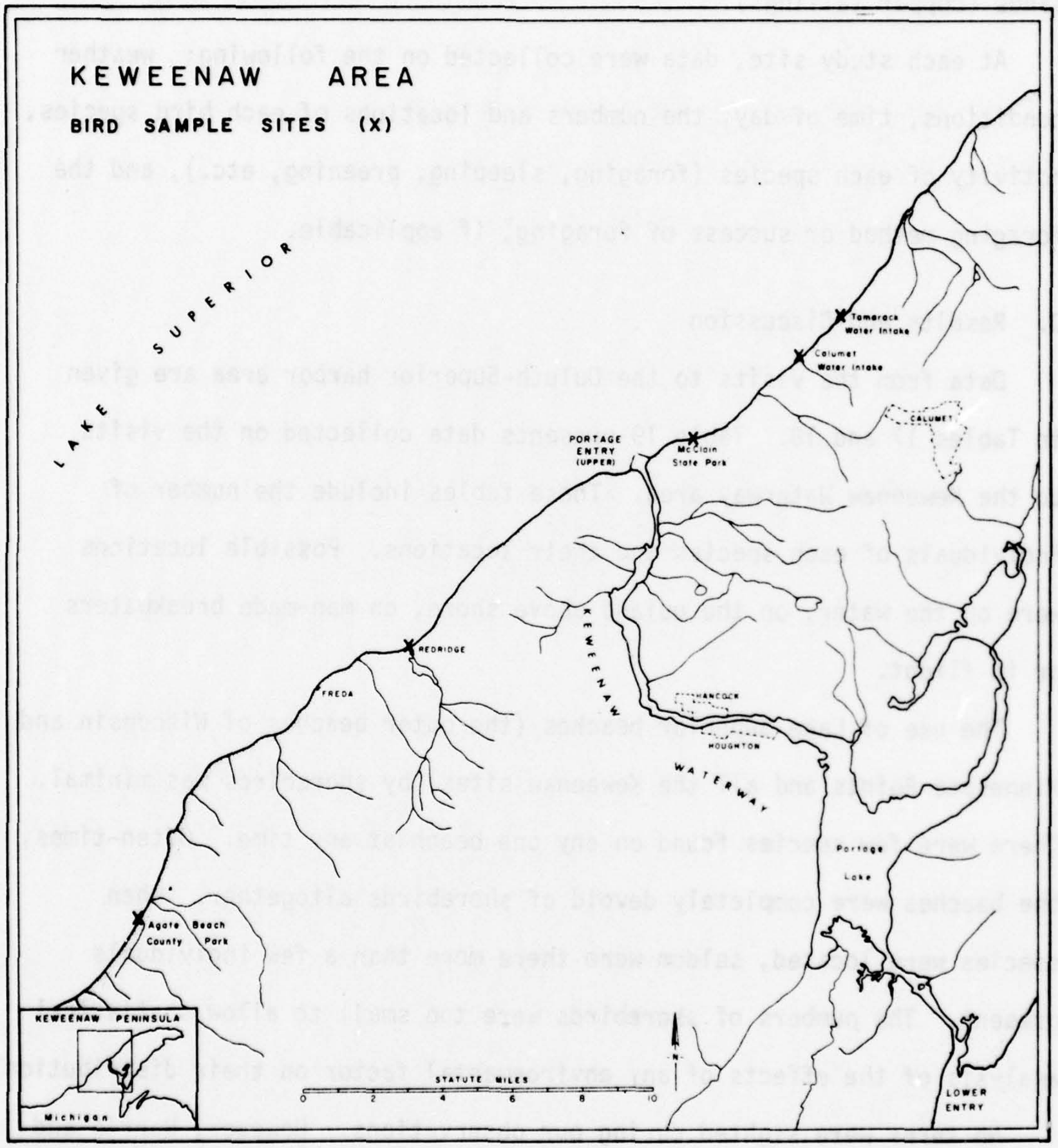
Visits were made to the study areas between the fall of 1972 and the spring of 1975. Four visits were made to the Duluth-Superior area and five visits were made to the northwest shore of the Keweenaw Peninsula. Duluth-Superior was visited three times in the fall (October, 1972, September 15-16, 1974, November 3-4, 1974) and once in the spring (May 4, 1975). The Keweenaw Peninsula was visited in the fall five times (September 12-13, 22-23, 1972; September 22-23, 1973; October 13-14, 1973; September 18-20, 1974). Individual study sites were chosen if there was the potential use of the area by migrant birds.

Twelve areas in the Duluth-Superior harbor area were observed (Figure 34). Four sites were located adjacent to Lake Superior, seven areas were located in Superior Bay and one was located in St. Louis Bay. Figure 34 also shows the location of the old offshore dump sites.

Five study sites in the vicinity of the Keweenaw Waterway were selected (Figure 35). During the summer and fall there are major lake currents from the southwest to the northeast (Adams, 1970; Ragotzkie, 1966). Spoil has been dumped in the past in a region 1 to 2 km west of the Portage entry. One of our study sites was located directly inshore from this dump site, two were downcurrent from the dump site and two were upcurrent from the dump site.

104 (Figure 33)




KEWEENAW AREA
BIRD SAMPLE SITES (X)
LAKE SUPERIOR
Tamarack Water Intake
Calumet Water Intake
CALUMET
PORTAGE ENTRY (UPPER)
McClain State Park
REDRIDGE
FREDA
KEWEENAW WATERWAY
HANCOCK
HOUGHTON
Portage Lake
Agate Beach County Park
KEWEENAW PENINSULA
Michigan
STATUTE MILES
0 2 4 6 8 10
LOWER ENTRY

Brief descriptions of the study site substrates are given in Table 15 for the Duluth-Superior sites and in Table 16 for the Keweenaw sites. The study sites varied from marshland to fine sands to piles of stamp sands (copper tailings).

At each study site, data were collected on the following: weather conditions, time of day, the numbers and locations of each bird species, activity of each species (foraging, sleeping, preening, etc.), and the foraging method or success of foraging, if applicable.

D. Results and Discussion

Data from the visits to the Duluth-Superior harbor area are given in Tables 17 and 18. Table 19 presents data collected on the visits to the Keweenaw Waterway area. These tables include the number of individuals of each species and their locations. Possible locations were on the water, on the upland above shore, on man-made breakwaters or in flight.

The use of Lake Superior beaches (the outer beaches of Wisconsin and Minnesota Points and all the Keweenaw sites) by shorebirds was minimal. There were few species found on any one beach at any time. Often-times, the beaches were completely devoid of shorebirds altogether. When species were located, seldom were there more than a few individuals present. The numbers of shorebirds were too small to allow statistical analysis of the effects of any environmental factor on their distribution.

No terns were sighted during our observations. However, Harris and Matteson (1975) observed common terns nesting in the Duluth-Superior harbor in summer.

The shores of Lake Superior received heavy usage by gulls. The gulls almost exclusively used areas that have been heavily altered by man. In the Duluth-Superior harbor area they congregated at the garbage dump at the base of Wisconsin Point where they would feed. When not feeding they would swim on the water directly offshore from this dump. Large numbers were also seen near the University of Wisconsin Research Station area at the tips of Wisconsin and Minnesota Points. The gulls would stand and sleep on the cement and rock breakwaters found there. Gulls were often seen flying between these breakwaters and the garbage dump. The gulls' use of areas other than those altered by man was minimal.

In the Keweenaw Waterway area gulls also concentrated in the vicinity of man's activities. The breakwaters at the northwest entry of the channel were heavily used by gulls for resting and sleeping. The other study areas were only lightly used by gulls. Much activity by gulls was observed in the waterway itself, particularly in the towns of Houghton and Hancock.

The abundance status of each species found in the Duluth-Superior harbor area are given in Table 20. Data was taken from an account of the Birds of Douglas County, Wisconsin by Bernard (1967) and from a list of Wisconsin birds by Barger et al. (1960). Most of the species found in the area are common migrants. However, two species which are considered rare, were sighted. The Glaucous Gull which is listed as rare is thought by Bernard (1967) to be a regular winter visitor to the area. We noticed it in early May feeding along a smelt net that was between the breakwaters at the tip of Minnesota Point. The Piping Plover is also listed as rare. They were once regular breeders on Lake Michigan, Lake Superior and some interior lakes of Wisconsin. They no longer breed in

these locations other than Lake Superior (Wisconsin DNR, 1973). The Endangered Species Committee of the Wisconsin Department of Natural Resources has placed the Piping Plover on its list of animals of "changing status"--that is, the stability of their population is uncertain. The only known active breeding location during the summer of 1974 was on Long Island in the Apostle Islands (Harris and Matteson, 1975).

Table 15: Substrate composition of the bird sample sites in the Duluth-Superior harbor.

Minnesota Point Outer Beach	broad sand beach
University of Wisconsin - Superior Research Station	cement and rock breakwaters, small sand beach
Wisconsin Point Outer Beach	broad sand beach
Garbage Dump	upland, garbage dump
Duckblind	marsh
Minnesota Point Inner Beach	narrow sand beach with 3' banks
BN Ore Docks	marsh
Hog Island	steep side, some marsh
Whaleback	narrow sand beach, some marsh
Park Point	upland, grass field
Yacht Club	steep banks, shrubs, small sand point

Table 16: Substrate composition of bird sample sites in Keweenaw Waterway vicinity.

Agate	wide sand beach
Redridge	stampsand (copper mine tailings)
McLain	wide sand beach, cement and rock breakwaters
Calumet	wide sand beach
Tamarack	narrow rocky beach

	Date	No birds	Semipalmated Plover	Piping Plover	Killdeer	Golden Plover	Spotted Sandpiper	Lesser Yellowlegs	Pectoral Sandpiper	Baird's Sandpiper	Semipalmated Sandpiper	Sanderling	Glaucous Gull	Herring Gull	Ring-billed Gull	Bonaparte's Gull
Minnesota Point Outer	9-16-74					1a	1									
	11-4-74											1a				
	5-4-75	X														
University of Wisconsin - Superior Research Station	9-14-74													102bd		
	9-15-74													84d		
	9-16-74						1							64d		
	11-3-74													220bd		
	11-4-74													120d		
	5-4-75													170abc		
Wisconsin Point Outer	9-14-74		7a									2a				
	9-15-74						1a					4a				
	11-3-74													8b		
	5-4-75			1a	4a									23f		
Garbage dump	9-14-74													760bfc		1b
	9-15-74													350bf	4b	
	11-3-74													700abc		

Table 17. Shorebirds and Gulls seen at the Duluth-Superior harbor study sites located on or adjacent to Lake Superior.

a = seen feeding, b = on water, c = on upland above shore,

d = on breakwater, f = flying

	Date	No birds	Semipalmated Plover	Piping Plover	Killdeer	Golden Plover	Spotted Sandpiper	Lesser Yellowlegs	Pectoral Sandpiper	Baird's Sandpiper	Semipalmated Sandpiper	Sanderling	Glaucous Gull	Herring Gull	Ring-billed Gull	Bonaparte's Gull
Yacht Club	9-15-74													1b	9b	
	9-16-74	X														
	11-3-74													1f		
	5-4-75				1a		1a								2	
Park Point	9-15-74					3ac			1ac	4ac						
	9-16-74					14ac				4ac						
	5-4-75	X														
Minnesota Point Inner	9-16-74					3	6a			3a				6f	2	
	11-4-74													1b		
	5-4-75				6c		4a							29f	2c	

Table 18. Shorebirds and Gulls seen at the Duluth-Superior study areas located in Superior and St. Louis Bays.

a = seen feeding, b = on water, c = on upland above shore,

d = on breakwater, f = flying

	Date	No birds	Semipalmated Plover	Piping Plover	Killdeer	Golden Plover	Spotted Sandpiper	Lesser Yellowlegs	Pectoral Sandpiper	Baird's Sandpiper	Semipalmated Sandpiper	Sanderling	Glaucous Gull	Herring Gull	Ring-billed Gull	Bonaparte's Gull
Duckblind	9-14-74													26f		
	9-15-74													15f		
	11-3-74	X														
	5-4-75													12b		
BN Ore Docks	11-4-74	X														
	5-4-75	X														
Hog Island	9-15-74	X														
	11-3-74	X														
Whaleback Tanker	9-15-74									1a				1f		
	11-3-74													5b		
	11-4-74													1f		
	5-4-75				1		1							3f		
Grassy Point	9-15-74				7	1a		1a			1			1	1	
	11-4-74	X														

Table 18 continued

	Date	No birds	Black-bellied Plover	Golden Plover	Killdeer	Ruddy Turnstone	Spotted Sandpiper	Solitary Sandpiper	Baird's Sandpiper	Sanderling	Glaucous Gull	Herring Gull	Ring-billed Gull
Agate Beach	9-13-72												2f
	9-22-72		1a										12a
	9-22-73		1a										13f
	9-17-74	X											
	9-18-74	X											
	9-19-74	X											
Redridge	9-12-72		1	7	4a					12a			1
	9-13-72			3a	2a					6a		2f	4
	9-22-72		±20									100	100
	9-22-73											100	100
	10-13-73									3a			
	9-18-74				7a				1a	3f		18	
	9-19-74			3a	7f		1a			2a		40	

Table 19. Shorebirds and Gulls seen at Keweenaw Waterway study area.

a = seen feeding, b = on water, c = on upland above shore,

d = on breakwater, f = flying

	Date	No birds	Black-bellied Plover	Golden Plover	Killdeer	Ruddy Turnstone	Spotted Sandpiper	Solitary Sandpiper	Baird's Sandpiper	Sanderling	Glaucous Gull	Herring Gull	Ring-billed Gull
McLain	9-12-72							1a			2	5	28
	9-13-72									5a	3	13	15
	9-22-72					1						25	10
	9-23-72												2
	9-22-73					1a						22f	
	9-23-73												2
	10-13-73			1a								59	59
	9-18-74											160	
	9-19-74			2a						5a		42	

Table 19 continued

	Date	No birds	Black-bellied Plover	Golden Plover	Killdeer	Ruddy Turnstone	Spotted Sandpiper	Solitary Sandpiper	Baird's Sandpiper	Sanderling	Glaucous Gull	Herring Gull	Ring-billed Gull
Calumet	9-12-72												1
	9-13-72		2a		4								
	9-22-72			1a						3a			
	9-23-72			4a						3a			
	9-22-73			1a						3a		+f	+f
	9-23-73			4a						3a			1f
	10-13-73											3f	
	10-14-73												
	9-18-74	X										2	
	9-20-74						2					2	
Tamarack	9-12-72											1	2
	9-13-72	X											
	9-22-72												3f
	9-22-73												2f
	10-13-73	X											
	9-18-74	X											

Table 19 continued

Table 20. Status of birds seen in Duluth-Superior harbor region. Data on regional status from Bernard (1967). Data on Wisconsin statewide status from Barger et al (1960).

Species	Local	Statewide
Semipalmated Plover	CT	FCT
Piping Plover	RT,RS	RT,RSn+e
Killdeer	CS,CT	CT,CS
Golden Plover	UT	UT
Spotted Sandpiper	CS,CT	CS,CT
Lesser Yellowlegs	CT,RS	CT
Pectoral Sandpiper	CT	CT
Baird's Sandpiper	CT	UT
Semipalmated Sandpiper	CT	CT
Sanderling	CT	CTe+n,UTinland
Herring Gull	CS,CT,UW	ATe,CTinland,AWe,CSe
Ring-billed Gull	CT,US	CT,FCSe,FCWe
Glaucous Gull	RW	RWe
Bonaparte's Gull	CT	CTe,UTinland

S	Summer	R	Rare
W	Winter	U	Uncommon
T	Transient	FC	Fairly Common
e	Eastern	C	Common
n	Northern	A	Abundant

E. Conclusions

1. Impact on gulls and terns

From our field observations, it is apparent that the presence of man's activities has more influence on the distribution and abundance of gulls in fall than does the quality of the beach environment of Lake Superior. Gulls were observed doing most of their foraging at garbage dumps. They also spent much of their time standing and sleeping on artificial breakwaters and piers. The observations of gulls on the sample sites that did not have these features were mostly of gulls flying along the shore between such localities. From our observations in both the Duluth-Superior harbor area and near the Keweenaw Waterway, we conclude that the changes in environmental quality associated with the offshore dumping of dredged material will have a minimal effect on gulls during the fall.

2. Impact on shorebirds

Our observations show that the use of Lake Superior beaches by migrating shorebirds is minimal. Because so few species and so few individuals were found using the beaches, we conclude that short-term analyses of the effects of offshore dumping on the shorebird community will be unmeasurable.

V. Appendices

APPENDIX A. July 1974. Numbers of organisms in each of three Ponar grabs, average ($\overline{x}$), standard deviation (s), and variance (s^2). See Fig. 35 at end of this appenidx for location of stations.

	Station 4					Station 3					Station 2				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
		1	7	1	0		0	15	2	0		0	14	2	6
#/Ponar grab		0	6	0	0		1	4	1	4		5	23	2	2
		2	6	2	0		0	9	1	7		0	27	3	0
$\overline{x}$		1.0	6.3	1.0	0		.3	9.3	1.3	3.7		1.7	21.3	2.3	2.7
s		1.0	.6	1.0	0		.6	5.5	.6	3.5		2.9	6.7	.6	3.1
s^2		1.0	.4	1.0	0		.4	30.3	.4	12.3		8.4	44.9	.4	9.6
$\#/m^2$		19.0	119.7	19.0	0		5.7	176.7	24.7	70.3		32.9	404.7	43.7	51.3
% of total		12	76	12	0		2	64	9	25		6	76	8	10
Depth (m)	26					24					23				
Bottom temp. (°C)															
Sediment	VERY FINE SAND + SILT.					VERY FINE SAND + SILT.					VERY FINE SAND + CLAY.				

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = *Pontoporeia*

APPENDIX A, continued.

	Station 1					Station 9					Station 12				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
		0	0	5	0		0	0	1	0		0	1	0	40
#/Ponar grab		0	0	4	0		0	1	0	0		0	4	0	53
		0	0	1	0		0	0	0	0		0	7	2	6
$\bar{x}$		0	0	3.3	0		0	.3	.3	0		0	3.7	.7	19.7
S		0	0	2.1	0		0	.6	.6	0		0	3.5	1.2	29.0
S^2		0	0	4.4	0		0	.4	.4	0		0	12.3	1.4	841.0
$\#/m^2$		0	0	62.7	0		0	5.7	5.7	0		0	70.3	13.3	374.3
% of total		0	0	100	0		0	50	50	0		0	15	3	32
Depth (m)	4					4					28				
Bottom temp. (°C)															
Sediment	MEDIUM FINE SAND.					MEDIUM SAND.					CLAY.				

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = *Pontoporeia*

APPENDIX A, continued.

	Station 19					Station 26					Station 11				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
		0	35	0	0		0	15	4	0		4	16	0	1
#/Ponar grab		0	41	0	0		0	4	6	0		0	99	1	0
		0	3	0	0		0	9	7	4		0	22	1	0
$\bar{x}$		0	26.3	0	0		0	9.3	5.7	1.3		1.3	19.0	.7	.3
s		0	20.4	0	0		0	5.5	1.5	2.3		2.3	3.0	.6	.6
s^2		0	416.2	0	0		0	30.3	2.3	5.3		5.3	9.0	.4	.4
#/m^2		0	499.7	0	0		0	176.7	108.3	24.7		24.7	361.0	13.3	5.7
% of total		0	100	0	0		0	57	35	8		6	89	3	1
Depth (m)	26					17					25				
Bottom temp. (°C)															
Sediment	CLAY + SILT.					FINE SAND.					VERY FINE MUD, SILT, + DEBRIS.				

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = <u>Pontoporeia</u>

APPENDIX A, continued.

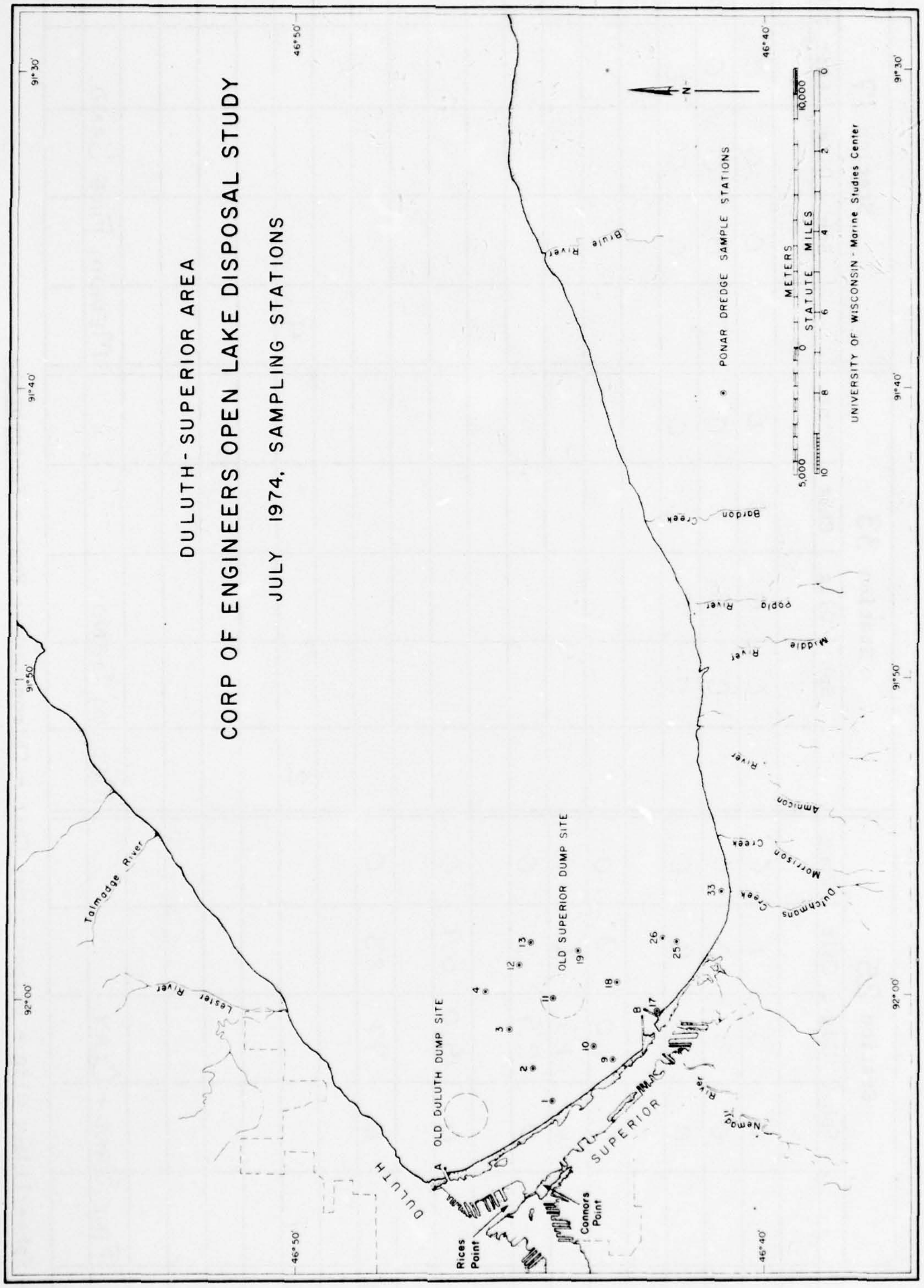
	Station 18					Station 10					Station 20				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
		0	65	11	0		0	9	0	0		0	9	0	0
#/Ponar grab		0	18	14	0		0	17	1	1		0	8	0	0
		0	43	3	0		0	42	4	0		1	3	2	18
$\bar{x}$		0	42.0	9.3	0		0	22.7	1.7	.3		.3	6.7	.7	6.0
s		0	23.5	5.7	0		0	17.2	2.1	.6		.6	3.2	1.2	10.4
s^2		0	552.3	32.5	0		0	295.8	4.4	.4		.4	10.2	1.4	103.2
$\#/m^2$		0	798.0	176.7	0		0	431.3	32.3	5.7		5.7	127.3	13.3	114.0
% of total		0	82	18	0		0	92	7	1		2	49	5	44
Depth (m)	19					21					28				
Bottom temp. (°C)															
Sediment	CLAY.					MEDIUM SAND, STICKS, + DEBRIS.					CLAY, SOME STICKS.				

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = Pontoporeia

APPENDIX A, continued.

	Station 25					Station 33					Station 17				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
		0	3	1	0		0	0	0	0		0	0	0	0
#/Ponar grab		0	0	0	0		0	0	0	0		0	0	0	0
		0	0	0	0		0	0	0	0		0	0	0	0
$\bar{x}$		0	1.0	.3	0										
s		0	1.7	.6	0										
s^2		0	2.9	.3	0										
#/m^2		0	19.0	5.7	0										
% of total		0	77	23	0										
Depth (m)	4					2					4				
Bottom temp. (°C)															
Sediment	FINE SAND + CLAY.					MEDIUM SAND.					MEDIUM FINE SAND.				

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = *Pontoporeia*


DULUTH-SUPERIOR AREA
CORP OF ENGINEERS OPEN LAKE DISPOSAL STUDY
JULY 1974, SAMPLING STATIONS
PONAR DREDGE SAMPLE STATIONS
METERS
STATUTE MILES
UNIVERSITY OF WISCONSIN - Marine Studies Center
OLD DULUTH DUMP SITE
OLD SUPERIOR DUMP SITE
DULUTH
SUPERIOR
Rices Point
Connors Point
Talmadge River
Lester River
Brule River
Bardon Creek
Poplar River
Middle River
Amnicon River
Morrison Creek
Dutchmans Creek
Nemadji River
46°50'
46°40'
92°00'
91°50'
91°40'
91°30'

APPENDIX B. September 1974. Numbers of organisms in each of three Ponar grabs, average ($\bar{x}$), standard deviation (s), and variance (s^2). See Fig. 36 at end of this appendix for location of stations.

	Station 16					Station 19					Station 21				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
		3	24	8	2		0	3	0	8		0	4	0	12
#/Ponar grab		15	21	4	19		1	8	0	4		0	8	0	19
		3	0	3	0		3	3	0	14		0	1	1	33
$\bar{x}$		7.0	15.0	5.0	7.0		1.3	4.7	0	8.7		0	4.3	.3	21.3
s		6.9	13.1	2.6	10.4		1.5	2.9	0	5.0		0	3.5	.6	10.7
s^2		47.6	171.6	6.8	108.2		2.3	8.4	0	25.0		0	12.3	.4	114.5
#/m^2		133.0	285.0	95.0	133.0		24.7	89.3	0	165.3		0	31.7	5.7	404.7
% of total		21	44	15	21		9	32	0	59		0	17	1	82
Depth (m)	25					25					32				
Bottom temp. (°C)															
Sediment															

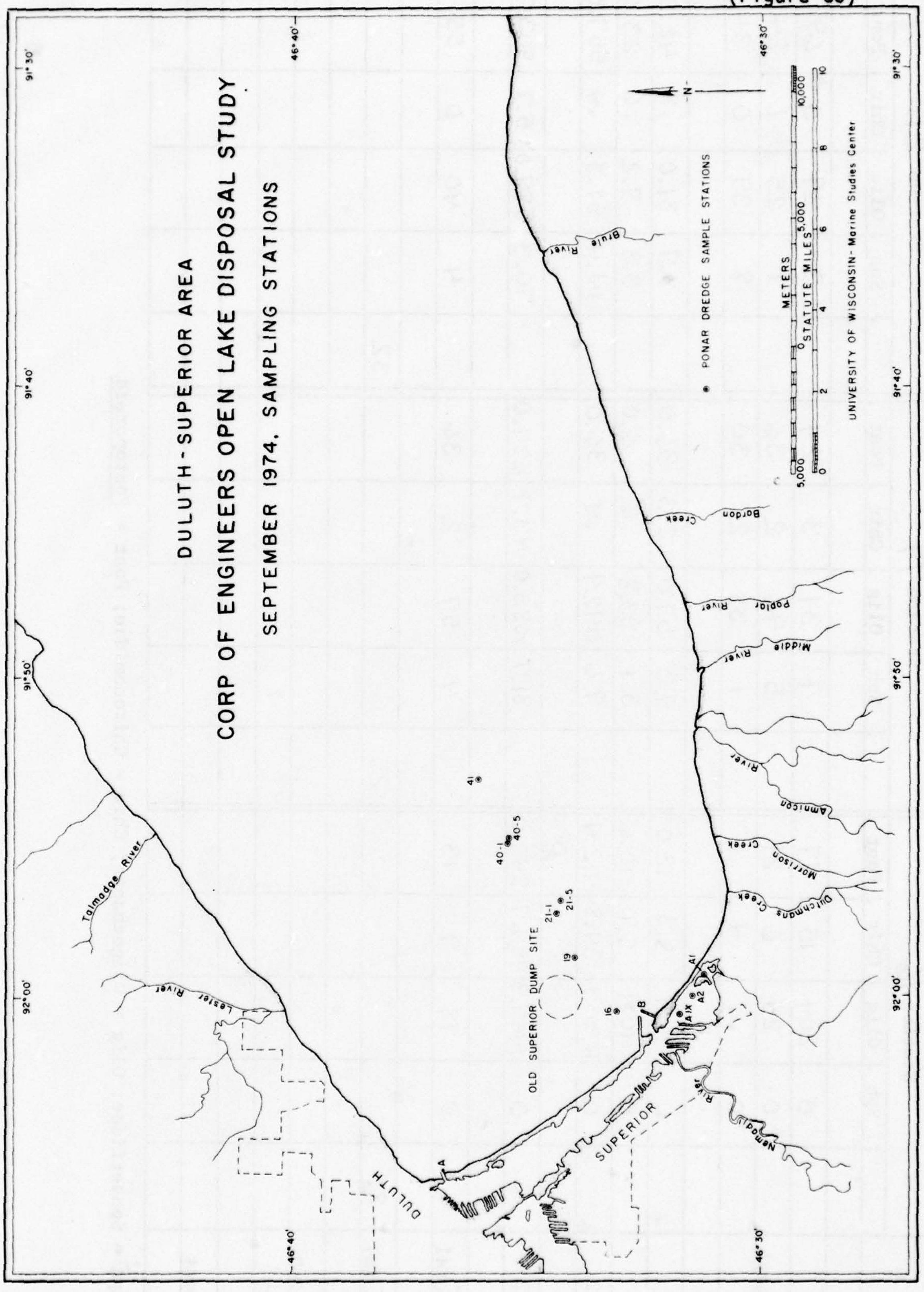
Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = *Pontoporeia*

APPENDIX B, continued.

	Station 40					Station 41					Station				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
							0	3	0	10					
		0	2	0	4		1	1	0	8					
#/Ponar grab		0	3	1	8		0	3	0	6					
		0	3	0	11		0	0	0	5					
$\bar{x}$		0	2.7	.3	7.7		.3	1.8	0	7.3					
s		0	.6	.6	3.5		.5	1.5	0	2.2					
s^2		0	.4	.4	12.3		.3	2.3	0	4.8					
$\#/m^2$		0	51.3	5.7	146.3		5.7	34.2	0	138.7					
% of total		0	25	3	72		3	19	0	78					
Depth (m)	43					53									
Bottom temp. (°C)															
Sediment															

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = <u>Pontoporeia</u>

(Figure 36)


DULUTH-SUPERIOR AREA
CORP OF ENGINEERS OPEN LAKE DISPOSAL STUDY
SEPTEMBER 1974, SAMPLING STATIONS
PONAR DREDGE SAMPLE STATIONS
METERS
STATUTE MILES
UNIVERSITY OF WISCONSIN-Marine Studies Center
OLD SUPERIOR DUMP SITE
DULUTH
SUPERIOR
Talmadge River
Lester River
Brule River
Bardon Creek
Poplar River
Middle River
Amnicon River
Morrison Creek
Dutchmans Creek
Nemadji River

APPENDIX C. October 1974. Numbers of organisms in each of three Ponar grabs, average ($\overline{x}$), standard deviation (s), and variance (s^2). See Fig. 37 at end of this appendix for location of stations.

	Station 16					Station 19					Station 21				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
		0	204	15	17		7	37	3	24		2	29	0	69
#/Ponar grab		0	25	6	21		5	96	2	36		1	25	1	24
		0	1	4	1		1	38	2	30		8	39	0	34
$\overline{x}$		0	76.7	8.3	13.0		4.3	57.0	2.3	36.0		3.7	31.0	.3	42.3
s		0	110.9	5.9	10.6		3.1	33.8	.6	6.0		3.8	7.2	.6	23.6
s^2		0	12,298.3	34.8	112.4		9.6	1142.4	.4	36.0		14.4	51.8	.4	557.0
#/m^2		0	1457.3	157.7	247.0		81.7	1083.0	43.7	684.0		70.3	589.0	5.7	803.7
% of total		0	78	9	13		4	57	2	36		4	40	0	55
Depth (m)	25					25					32				
Bottom temp. (°C)															
Sediment															

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = Pontoporeia

APPENDIX C, continued.

	Station 40					Station 42					Station 43				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
		0	3	0	23		0	6	1	11		0	0	0	11
#/Ponar grab		0	0	0	30		0	4	1	0		0	0	0	2
		0	3	0	26		0	12	1	5		0	0	1	6
$\bar{x}$		0	2.0	0	26.3		0	7.3	1	5.3		0	0	.3	6.3
s		0	1.7	0	3.5		0	4.2	0	5.5		0	0	.6	4.5
s^2		0	2.9	0	12.3		0	17.6	0	30.3		0	0	.4	20.3
$\#/m^2$		0	38.0	0	499.7		0	133.7	19.0	100.7		0	0	5.7	119.7
% of total		0	7	0	93		0	54	7	39		0	0	5	96
Depth (m)	43										78				
Bottom temp. (°C)															
Sediment															

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = *Pontoporeia*

APPENDIX C, continued.

	Station 46					Station 51					Station 52				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
												0	8	0	14
		2	16	0	8		0	15	1	27		0	8	0	6
#/Ponar grab		0	17	1	0		0	12	1	9		0	11	0	12
		0	16	0	5		0	14	0	15		0	10	1	56
$\bar{x}$		.7	16.3	.3	4.3		0	13.7	.7	17.0		0	9.3	.3	22.0
s		1.2	.6	.6	4.0		0	.5	.6	9.2		0	1.5	.5	22.9
s^2		1.4	.4	.4	16.0		0	.3	.4	84.6		0	2.3	.3	524.4
$\#/m^2$		13.5	309.7	5.7	81.7		0	260.3	13.3	323.0		0	176.7	5.7	418.0
% of total		3	76	1	20		0	44	2	54		0	29	1	70
Depth (m)	82					54					50				
Bottom temp. (°C)															
Sediment															

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = *Pontoporeia*

APPENDIX C, continued.

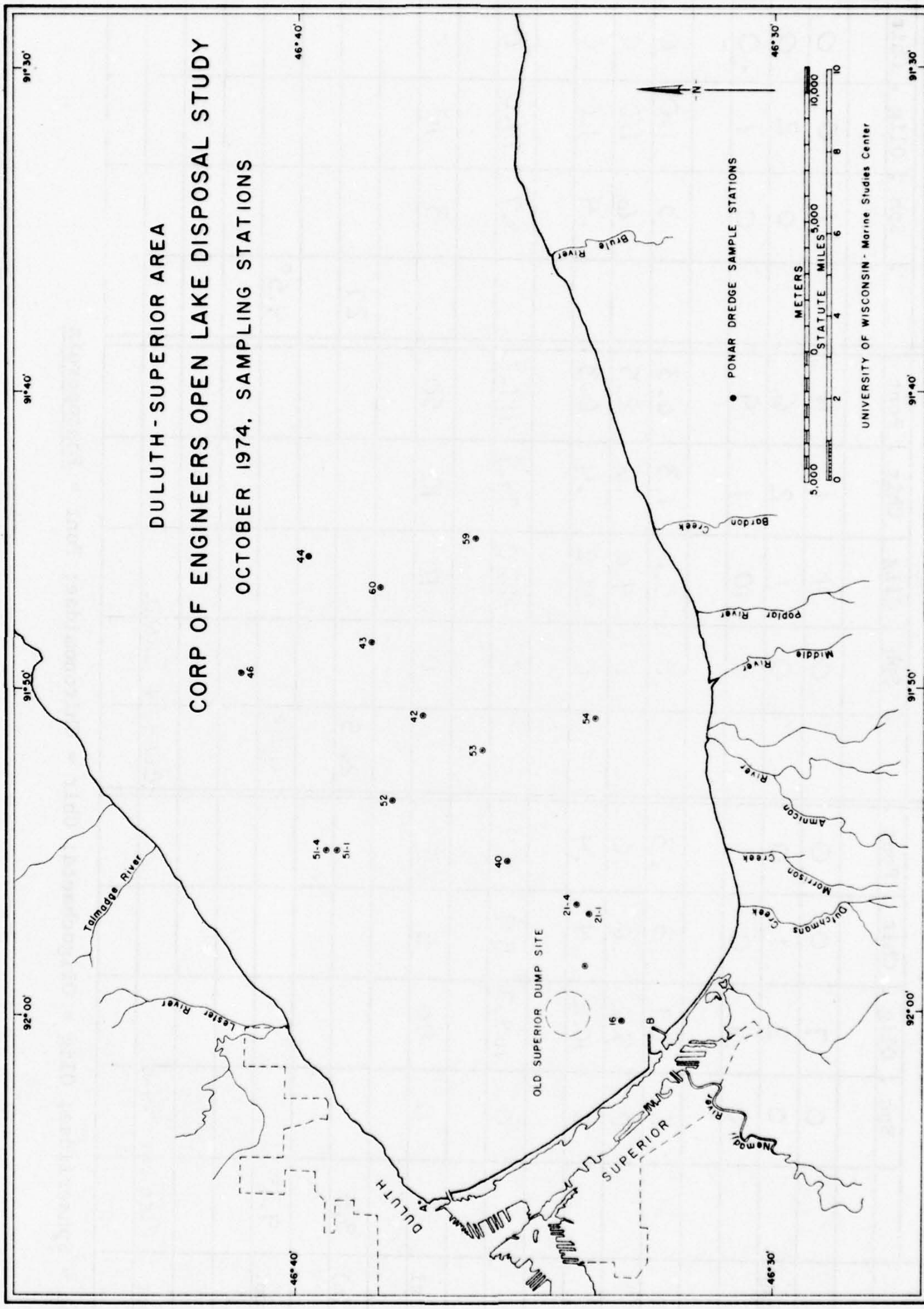
		Station 59					Station 60					Station 44			
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
		0	3	2	37		0	0	0	6		0	4	3	8
#/Ponar grab		1	0	0	75		0	0	1	14		0	7	0	8
		0	0	1	32		0	1	1	6		0	0	0	19
$\bar{x}$		.3	1.0	1.0	48.0		0	.3	.7	8.7		0	3.7	1.0	11.7
s		.6	1.7	1.0	23.5		0	.6	.6	4.6		0	3.5	1.7	6.4
s^2		.4	2.9	1.0	552.3		0	.4	.4	21.2		0	12.3	2.9	41.0
$\#/m^2$		5.7	19.0	19.0	912.0		0	5.7	13.3	165.3		0	70.3	19.0	222.3
% of total		1	2	2	95		0	3	7	90		0	23	6	71
Depth (m)	140														
Bottom temp. (°C)															
Sediment															

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = *Pontoporeia*

APPENDIX C, continued.

	Station 53					Station					Station				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
		0	14	1	85										
#/Ponar grab		0	1	0	7										
$\bar{x}$		0	7.5	.5	46.0										
s		0	9.2	.7	55.2										
s^2		0	84.6	.5	3047.0										
$\#/m^2$		0	142.5	9.5	874.0										
% of total		0	14	1	85										
Depth (m)	44														
Bottom temp. (°C)															
Sediment															

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = *Pontoporeia*


DULUTH - SUPERIOR AREA
CORP OF ENGINEERS OPEN LAKE DISPOSAL STUDY
OCTOBER 1974, SAMPLING STATIONS
PONAR DREDGE SAMPLE STATIONS
METERS
STATUTE MILES
UNIVERSITY OF WISCONSIN - Marine Studies Center
OLD SUPERIOR DUMP SITE
Talmadge River
Lester River
Brule River
Bardon Creek
Poplar River
Middle River
Amnicon River
Morrison Creek
Dutchmans Creek
Nemadji River
DULUTH
SUPERIOR

APPENDIX D. May 1975. Numbers of organisms in each of three Ponar grabs, average ($\overline{x}$), standard deviation (s), and variance (s^2). See Fig. 38 at end of this appendix for location of stations.

	Station 1					Station 3					Station 6				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
		0	7	0	0		0	4	1	4		1	0	0	13
#/Ponar grab		0	2	1	0		0	1	2	6		0	2	0	11
		0	8	0	1		0	10	1	9		0	1	0	2
$\overline{x}$		0	5.7	.3	.3		0	5.0	1.3	6.3		.3	1.0	0	8.7
s		0	3.2	.6	.6		0	4.6	.6	2.5		.6	1.0	0	5.9
s^2		0	10.2	.4	.4		0	21.2	.4	6.3		.4	1.0	0	34.8
#/m^2		0	108.3	5.7	5.7		0	95.0	24.7	119.7		5.7	19.0	0	165.3
% of total		0	90	5	5		0	40	10	50		3	10	0	87
Depth (m)	3.5					26.5					27				
Bottom temp. (°C)	9.1°					4.4°					4.5°				
Sediment	MEDIUM SAND.					CLAYEY SAND.									

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = Pontoporeia

APPENDIX D, continued.

	Station 7					Station 10					Station 15				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
		0	0	0	3		0	1	0	0		0	4	5	3
#/Ponar grab		0	10	1	3		0	1	0	0		0	3	1	6
		0	4	4	3		0	7	0	1		0	1	0	0
$\bar{X}$		0	4.7	1.7	3.0		0	3.0	0	.3		0	2.7	2.0	3.0
S		0	5.0	2.1	0		0	3.5	0	.6		0	1.5	2.6	3.0
S^2		0	25.0	4.4	0		0	12.2	0	.4		0	2.2	6.8	9.0
$\#/m^2$		0	89.3	32.3	57.0		0	57.0	0	5.7		0	51.3	33.0	57.0
% of total		0	50	13	32		0	91	0	9		0	35	26	39
Depth (m)	21					19.5					18.3				
Bottom temp. (°C)	4.6°					4.8°					4.75°				
Sediment	CLAYEY	SAND.				FINE	SAND.				FINE	SAND.			

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = Pontoporeia

APPENDIX D, continued.

	Station 17					Station 19					Station 24				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
		1	7	2	0		0	4	6	26		0	121	11	28
#/Ponar grab		0	2	4	1							0	87	7	24
		0	9	2	0		0	49	28	43		0	11	12	13
$\bar{x}$		.3	6.0	2.7	.3		0	26.5	17.0	34.5		0	73.0	10.0	21.7
s		.6	3.6	1.2	.6		0	31.3	15.6	12.0		0	56.3	2.6	7.8
s^2		.4	12.9	1.4	.4		0	1011.2	243.4	144.0		0	3169.7	6.3	60.8
#/m^2		5.7	114.0	51.3	5.7		0	503.5	323.0	655.5		0	1387.0	190.0	412.3
% of total		3	65	29	3		0	34	22	44		0	70	10	21
Depth (m)	11.5					22									
Bottom temp. (°C)	9.6°					4.2°					4.3°				
Sediment	CLAYEY SAND.					CLAYEY SAND.					SANDY CLAY.				

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = *Pontoporeia*

APPENDIX D, continued.

	Station 25					Station 33					Station 34				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
		1	4	4	1		0	3	0	0		0	10	2	2
#/Ponar grab		0	4	3	2		0	0	0	0		0	2	4	4
		0	4	7	3		0	3	0	0		0	0	0	1
$\bar{x}$		.3	4.0	4.7	2.0		0	2.0	0	0		0	4.0	2.0	2.3
s		.6	0	2.1	1.0		0	1.7	0	0		0	5.3	2.0	1.5
s^2		.4	0	4.4	1.0		0	2.9	0	0		0	28.1	4.0	2.2
$\#/m^2$		5.7	76.0	89.3	33.0		0	33.0	0	0		0	76.0	33.0	43.7
% of total		3	36	43	18		0	100	0	0		0	48	24	28
Depth (m)	12.5					3.5					12				
Bottom temp. (°C)	6.1°					11.2°					4.1°				
Sediment	FINE	SAND.													

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = *Pontoporeia*

APPENDIX D, continued.

	Station 35					Station 37					Station 38				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
		0	49	3	1		0	54	9	43		0	10	0	29
#/Ponar grab		0	18	0	0		4	82	8	60		0	9	1	17
		0	11	3	4		0	65	2	21		4	19	1	32
$\bar{x}$		0	26.0	2.0	1.7		1.3	67.0	6.3	41.3		1.3	12.7	.7	26.0
s		0	20.2	1.7	2.1		2.3	14.1	3.8	19.6		2.3	5.5	.6	7.9
s^2		0	403.0	2.9	4.4		5.3	198.3	14.4	384.2		5.3	30.2	.4	62.4
#/m^2		0	494.0	38.0	32.3		24.7	1273.0	119.7	784.7		24.7	241.3	13.3	494.0
% of total		0	88	7	6		1	58	5	36		3	31	2	64
Depth (m)	19					22					24				
Bottom temp. (°C)	4.0°					4.2°					4.0°				
Sediment	COARSE	SAND.									CLAYEY	SAND.			

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = <u>Pontoporeia</u>

APPENDIX D, continued.

	Station 39					Station 40					Station 41				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
		0	3	0	5		0	7	2	24		0	6	7	23
#/Ponar grab		0	6	3	10		1	4	1	7		0	3	9	23
		5	0	1	32		3	4	1	3		1	6	8	27
$\bar{x}$		1.7	3.0	1.3	15.7		1.3	5.0	1.3	11.3		.3	5.0	3.0	26.0
s		2.9	3.0	1.5	14.4		1.5	1.7	.6	11.2		.6	1.7	1.0	2.6
s^2		8.4	9.0	2.2	207.4		2.2	2.9	.4	125.4		.4	2.9	1.0	6.8
#/m^2		32.3	57.0	24.7	298.3		24.7	95.0	24.7	214.7		5.7	103.3	133.7	494.0
% of total		8	14	6	72		7	26	7	60		1	15	19	66
Depth (m)	27					30									
Bottom temp. (°C)	4.0°					3.9°					4.3°				
Sediment	SANDY CLAY.					SANDY CLAY.					SANDY CLAY.				

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = *Pontoporeia*

APPENDIX D, continued.

	Station 42					Station 43					Station 44				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
		0	6	1	4		1	2	1	20		0	6	3	44
#/Ponar grab		3	176	0	7		0	11	8	35		0	0	9	11
		0	55	1	7		0	0	0	18		0	4	0	8
$\bar{x}$		1.0	79.0	.7	6.0		.3	4.3	3.0	24.3		0	3.3	4.0	21.0
s		1.7	87.5	.6	1.7		.6	5.9	4.4	9.3		0	3.1	4.6	20.0
s^2		2.9	7656.2	.4	2.9		.4	34.3	19.4	86.5		0	9.6	21.2	400.0
#/m^2		19.0	1501.0	13.3	114.0		5.7	81.7	57.0	461.7		0	62.7	76.0	399.0
% of total		1	91	1	7		1	13	9	76		0	12	14	74
Depth (m)	20					27					25				
Bottom temp. (°C)	5.2°					4.9°					4.8°				
Sediment	CLAYEY SAND					CLAYEY SAND					CLAYEY SAND, DETRITUS.				

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = *Pontoporeia*

APPENDIX D, continued.

	Station 45					Station 46					Station 47				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
		0	19	24	3		0	5	3	3		0	1	5	16
#/Ponar grab		0	1	1	29		0	3	0	0		0	1	1	11
		0	10	0	10		0	3	3	4		1	7	11	19
$\bar{x}$		0	10.0	8.3	14.0		0	3.7	2.0	2.3		.3	3.0	5.7	15.3
s		0	9.0	13.6	13.5		0	1.2	1.7	2.1		.6	3.5	5.0	4.0
s^2		0	81.0	184.9	182.2		0	1.4	2.9	4.4		.4	12.2	25.0	16.0
$\#/m^2$		0	190.0	157.7	266.0		0	70.3	38.0	43.7		5.7	57.0	108.3	290.7
% of total		0	31	26	43		0	46	25	29		1	12	23	63
Depth (m)	25.5					29					33				
Bottom temp. (°C)	4.1°					4.5°					4.6°				
Sediment	CLAYEY SAND w/ ORGANIC.					SANDY CLAY.					SANDY CLAY.				

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = *Pontoporeia*

APPENDIX D, continued.

	Station 48					Station 49					Station 50				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
		0	10	20	9		0	0	0	6		0	19	1	7
#/Ponar grab		0	24	17	3		0	0	0	6		0	5	2	7
		0	14	8	10		0	0	1	7					
$\bar{x}$		0	16.0	15.0	7.3		0	0	.3	6.3		0	12.0	1.5	7.0
s		0	7.2	6.2	3.8		0	0	.6	.6		0	9.9	.7	0
s^2		0	51.3	38.4	14.4		0	0	.4	.4		0	98.0	.5	0
#/m^2		0	304.0	285.0	138.7		0	0	5.7	119.7		0	228.0	28.5	133.0
% of total		0	42	39	19		0	0	5	95		0	59	7	34
Depth (m)	25										24.7				
Bottom temp. (°C)															
Sediment	CLAYEY SAND, ORGANICS.					CLAYEY SAND.					FINE SAND w ORGANICS.				

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = *Pontoporeia*

APPENDIX D, continued.

	Station 51					Station 52					Station 53				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
		0	1	2	4		0	7	1	5		2	59	4	16
#/Ponar grab		0	3	0	8		1	16	2	7		0	15	2	14
		0	8	0	5		0	3	1	5		2	36	1	10
$\bar{x}$		0	4.0	.7	5.7		.3	3.7	1.3	5.7		1.3	36.7	2.3	13.3
S		0	3.6	1.2	2.1		.6	6.7	.6	1.2		1.2	22.0	1.5	3.1
S^2		0	12.9	1.4	4.4		.4	44.9	.4	1.4		1.4	434.0	2.2	9.6
#/m^2		0	76.0	13.3	108.3		5.7	165.3	24.7	108.3		24.7	697.3	43.7	252.7
% of total		0	38	7	55		2	54	3	36		2	68	4	25
Depth (m)	26.5					25					25.7				
Bottom temp. (°C)															
Sediment	CLAYEY SAND.					CLAYEY SAND.									

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = Pontoporeia

APPENDIX D, continued.

	Station 54					Station 55					Station 56				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
		0	2	0	2		0	15	0	10		0	4	2	7
#/Ponar grab		0	1	4	10		0	7	0	6		0	0	2	19
		1	1	0	5		0	10	2	10		1	2	0	25
$\bar{x}$		.7	1.3	1.3	5.7		0	10.7	.7	3.7		.3	2.0	1.3	17.0
s		6	.6	2.3	4.0		0	4.0	1.2	2.3		.6	2.0	1.2	9.2
s^2		.4	.4	5.3	16.0		0	16.0	1.4	5.3		.4	4.0	1.4	34.6
$\#/m^2$		13.3	24.7	24.7	108.3		0	203.3	13.3	165.3		5.7	33.0	24.7	323.0
% of total		8	14	14	63		0	53	3	43		1	10	6	83
Depth (m)	25					28					30				
Bottom temp. (°C)	5.3°					4.8°					4.8°				
Sediment	CLAYEY SAND.					CLAYEY SAND.					CLAYEY SAND.				

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = Pontoporeia

APPENDIX D, continued.

	Station 57					Station 58					Station 59				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
#/Ponar grab		2	24	6	32		0	2	0	8		0	9	1	0
		2	5	2	28		0	5	3	14		0	5	3	2
		0	1	0	11		0	2	2	22		0	0	1	0
$\bar{x}$		1.3	10.0	2.7	23.7		0	3.0	1.7	14.7		0	4.7	1.7	.7
s		1.2	12.3	3.1	11.2		0	1.7	1.5	7.0		0	4.5	1.2	1.2
s^2		1.4	151.3	9.6	125.4		0	2.9	2.2	49.0		0	20.2	1.4	1.4
$\#/m^2$		24.7	190.0	51.3	450.3		0	57.0	32.3	279.3		0	89.3	32.3	13.3
% of total		3	27	7	63		0	15	9	76		0	66	24	10
Depth (m)	34					35.5					8				
Bottom temp. (°C)	4.3°					4.3°					7.4°				
Sediment	SANDY CLAY.					SANDY CLAY.									

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = <u>Pontoporeia</u>

APPENDIX D, continued.

	Station 60					Station 61					Station 62				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
		0	11	1	1		1	2	0	6		1	28	5	98
#/Ponar grab		0	16	0	4		2	3	1	12		2	12	6	166
		1	7	0	3		0	0	1	3		2	7	5	151
$\bar{x}$		.3	11.3	.3	2.7		1.0	1.7	.7	7.0		1.7	15.7	5.3	138.3
s		.6	4.5	.6	1.5		1.0	1.5	.6	4.6		.6	11.0	.6	35.7
s^2		.4	20.2	.4	2.2		1.0	2.2	.4	21.2		.4	121.0	.4	1274.5
$\#/m^2$		5.7	214.7	5.7	51.3		19.0	32.3	13.3	133.0		32.3	298.3	100.7	2627.7
% of total		2	77	2	18		10	16	7	67		1	10	3	86
Depth (m)	26					27.5					27				
Bottom temp. (°C)	4.7°					4.4°					4.7°				
Sediment	CLAYEY SAND.					SANDY CLAY.					SANDY CLAY.				

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = *Pontoporeia*

APPENDIX D, continued.

	Station 63					Station 64					Station 65				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
		0	6	12	32		0	23	1	34		0	3	1	0
#/Ponar grab		1	14	5	21		2	37	6	22		1	20	2	5
		1	10	2	39		0	10	2	18		0	2	1	0
$\bar{x}$		.7	10.0	6.3	30.7		.7	23.3	3.0	24.7		.3	8.3	1.3	1.7
S		.6	4.0	5.1	9.1		1.2	13.5	2.6	8.3		.6	10.1	.6	2.9
S^2		.4	16.0	26.0	82.8		1.4	132.2	6.8	68.9		.4	102.0	.4	8.4
$\#/m^2$		13.3	190	119.7	583.3		13.3	442.7	57.0	469.3		5.7	157.7	24.7	32.3
% of total		1	21	13	64		1	45	6	48		3	72	11	15
Depth (m)	30					32.5					24				
Bottom temp. (°C)	4.1°					4.2°					4.5°				
Sediment	Sandy Clay.										Sandy Clay.				

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = *Pontoporeia*

APPENDIX D, continued.

	Station 66					Station 67					Station 68				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
		0	20	3	35		0	13	2	11		0	9	0	0
#/Ponar grab		0	11	3	22		1	23	2	25		0	1	2	0
		0	32	5	41		0	9	1	18		0	1	2	1
$\bar{x}$		0	21.0	3.7	32.7		.3	15.0	1.7	18.0		0	3.7	1.3	.3
s		0	10.5	1.2	9.7		.6	7.2	.6	7.0		0	4.6	1.2	.6
s^2		0	110.2	1.4	94.1		.4	51.3	.4	49.0		0	21.2	1.4	.4
$\#/m^2$		0	399.0	70.3	621.3		5.7	285.0	32.3	342.0		0	70.3	24.7	5.7
% of total		0	37	6	57		1	43	5	51		0	70	25	6
Depth (m)	30					32					7.5				
Bottom temp. (°C)	4.5°					4.2°					11.1°				
Sediment						SANDY CLAY.					MEDIUM SAND.				

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = <u>Pontoporeia</u>

APPENDIX D, continued.

	Station 69					Station 71					Station 72				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
		0	13	19	28		0	17	1	5		0	19	1	6
#/Ponar grab		0	17	43	39		0	3	1	4		1	16	2	29
		0	6	8	35		7	2	2	21		0	10	2	4
$\bar{x}$		0	12.0	33.3	34.0		2.3	7.3	1.3	10.0		.3	15.0	1.7	13.0
s		0	5.6	22.1	5.6		4.0	3.4	.6	9.5		.6	4.6	.6	13.9
s^2		0	31.4	488.4	31.4		16.0	70.6	.4	90.2		.4	21.2	.4	193.2
$\#/m^2$		0	223.0	632.7	646.0		43.7	138.7	24.7	190.0		5.7	285.0	32.3	247.0
% of total		0	15	42	43		11	35	6	48		1	50	6	43
Depth (m)	23					24.5					22.5				
Bottom temp. (°C)	4.4°					4.5°					4.6°				
Sediment	CLAYEY SAND, SANDY CLAY w/ FINE DETRITUS.					FINE SAND.					FINE SAND.				

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = Pontoporeia

APPENDIX D, continued.

	Station 73					Station 74					Station 75				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
		0	4	0	8		0	0	4	27		0	11	3	31
#/Ponar grab		0	4	10	20		0	23	2	19		0	11	7	59
		0	1	0	30		0	7	3	29		0	18	3	94
$\bar{x}$		0	3.0	3.3	19.3		0	10.0	3.0	25.0		0	13.3	4.3	61.3
s		0	1.7	5.8	11.0		0	11.3	1.0	5.3		0	4.0	2.3	31.6
s^2		0	2.9	33.6	121.0		0	139.2	1.0	29.1		0	16.0	5.3	998.6
#/m^2		0	57.0	62.7	366.7		0	190.0	57.0	475.0		0	252.7	81.7	1164.7
% of total		0	12	13	75		0	26	8	66		0	17	5	78
Depth (m)	23.5					25					28				
Bottom temp. (°C)	4.5°					4.5°					4.5°				
Sediment	FINE SAND.					CLAYEY SAND.					CLAYEY SAND.				

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = *Pontoporeia*

APPENDIX D, continued.

	Station 76					Station 77					Station 78				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
#/Ponar grab		0	31	3	25		0	15	0	22		0	6	2	15
		0	16	2	10		0	2	3	19		0	4	4	24
		2	20	2	37		0	2	0	7		0	14	0	7
$\bar{x}$		.7	22.3	2.3	24.0		0	6.3	1.0	16.0		0	8.0	2.0	15.3
S		1.2	7.8	.6	13.5		0	7.5	1.7	7.9		0	5.3	2.0	8.5
S^2		1.4	60.8	.4	182.2		0	56.2	2.9	62.4		0	28.1	4.0	72.2
#/m^2		13.3	423.7	43.7	456.0		0	119.7	19.0	304.0		0	152.0	38.0	290.7
% of total		1	45	5	49		0	27	4	69		0	32	8	60
Depth (m)	30					31					32				
Bottom temp. (°C)	4.3°					4.4°					4.3°				
Sediment	CLAYEY SAND.					CLAYEY SAND.					SANDY CLAY.				

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = Pontoporeia

APPENDIX D, continued.

	Station 79					Station 80					Station 81				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
		0	2	3	4		0	23	6	20		0	34	0	22
#/Ponar grab		0	15	0	4		0	5	7	36		0	6	0	27
		0	39	8	2		0	21	7	16		0	13	1	43
$\bar{x}$		0	18.7	3.7	3.3		0	16.3	6.7	24.0		0	17.7	.3	30.7
s		0	13.8	4.0	1.2		0	9.9	.6	10.6		0	14.6	.6	11.0
s^2		0	353.4	16.0	1.4		0	98.0	.4	112.4		0	213.2	.4	121.0
$\#/m^2$		0	355.3	70.3	62.7		0	309.7	127.3	456.0		0	336.3	5.7	583.3
% of total		0	73	14	13		0	35	14	51		0	36	1	63
Depth (m)	22					27.5									
Bottom temp. (°C)	4.4°					4.4°									
Sediment	CLAYEY SAND, FINE SAND.					CLAYEY SAND.					SANDY CLAY.				

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = Pontoporeia

APPENDIX D, continued.

	Station 82					Station 83					Station 84				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
#/Ponar grab		0	13	7	24		0	80	9	4		2	40	13	23
		0	13	2	25		4	3	4	3		1	30	19	41
		0	3	0	6							6	101	20	73
$\bar{x}$		0	11.3	3.0	18.3		2.0	44.0	6.5	6.0		3.0	57.0	17.3	45.7
s		0	7.6	3.6	10.7		2.8	50.9	3.5	2.8		2.6	38.4	3.8	25.3
s^2		0	57.8	12.9	114.5		7.8	2590.8	12.2	7.8		6.7	1474.6	14.4	640.1
$\#/m^2$		0	214.7	57.0	347.7		38.0	836.0	123.5	114.0		57.0	1083.0	328.7	868.3
% of total		0	35	9	56		3	75	11	10		2	46	14	37
Depth (m)	31					20					25.5				
Bottom temp. (°C)	4.1°					4.6°					4.4°				
Sediment	CLAYEY SAND, w ROCKS.					CLAYEY SAND.					SANDY CLAY.				

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = Pontoporeia

APPENDIX D, continued.

	Station 85					Station 86					Station 87				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
		0	0	3	2		3	121	11	18		4	83	15	22
#/Ponar grab		0	71	2	19		1	22	6	11		1	134	27	22
		1	36	3	27		3	51	7	24		0	5	5	8
$\bar{X}$		.3	35.7	2.7	16.0		2.3	64.7	8.0	17.7		1.7	74.0	15.7	17.3
S		.6	35.5	.6	12.8		1.2	50.9	2.6	6.5		2.1	65.0	11.0	8.1
S^2		.4	1260.2	.4	163.8		1.4	2590.8	6.7	42.2		4.4	4225.0	121.0	65.6
$\#/m^2$		5.7	678.3	51.3	304.0		43.7	1229.3	152.0	336.3		32.3	1406.0	298.3	323.7
% of total		1	65	5	29		2	70	9	19		2	63	14	16
Depth (m)						27					18				
Bottom temp. (°C)	4.3°					4.2°					4.6°				
Sediment	CLAYEY SAND.					CLAYEY SAND.					CLAYEY SAND.				

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = _Pontoporeia_

APPENDIX D, continued.

	Station 88					Station 89					Station 91				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
		0	4	3	2		0	3	1	3		0	3	3	4
#/Ponar grab		0	5	2	0		0	3	0	4		0	0	0	0
		0	23	7	0		0	3	0	5		0	3	2	5
$\bar{X}$		0	10.7	4.0	.7		0	3.0	.3	4.0		0	2.0	1.7	3.0
S		0	10.7	2.6	1.2		0	0	.6	1.0		0	1.7	1.5	2.6
S^2		0	114.5	6.8	1.4		0	0	.4	1.0		0	2.9	2.2	6.8
$\#/m^2$		0	203.3	76.0	13.3		0	57.0	5.7	76.0		0	33.0	32.3	57.0
% of total		0	69	26	5		0	41	4	55		0	30	25	45
Depth (m)	20					19.5					13.5				
Bottom temp. (°C)	4.6°					4.4°					6.1°				
Sediment	FINE SAND, MEDIUM SAND, CLAYEY SAND.					FINE SAND.									

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = Pontoporeia

APPENDIX D, continued.

	Station 93					Station 94					Station 95				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
#/Ponar grab		0	4	1	0		0	0	4	16		0	2	1	2
		0	1	1	0		0	2	2	2					
		0	1	1	0										
$\bar{x}$		0	2.0	1.0	0		0	1.0	3.0	9.0		0	2	1	2
s		0	1.7	0	0		0	1.4	1.4	9.9					
s^2		0	2.9	0	0		0	1.9	1.9	93.0					
$\#/m^2$		0	33.0	19.0	0		0	19.0	57.0	171.0		0	38	19	38
% of total		0	67	33	0		0	8	23	69		0	40	20	40
Depth (m)	15					10									
Bottom temp. (°C)	5.6°					8.0°									
Sediment	FINE SAND, SMALL ROCKS + VERY SMALL QUARTZITE SAND.					ROCK.					PEA GRAVEL + MEDIUM SAND.				

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = *Pontoporeia*

APPENDIX D, continued.

	Station 96					Station 97					Station 98				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
		0	0	1	1		0	1	2	0		0	1	1	0
#/Ponar grab		0	5	0	1		0	3	0	0		0	1	0	0
							0	1	0	0					
$\bar{x}$		0	2.5	.5	1.0		0	1.7	.7	0		0	1.0	.5	0
s		0	3.5	.7	0		0	1.2	1.2	0		0	0	.7	0
s^2		0	12.2	.5	0		0	1.4	1.4	0		0	0	.5	0
#/m^2		0	47.5	9.5	19.0		0	32.3	13.3	0		0	19.0	9.5	0
% of total		0	63	13	25		0	71	29	0		0	67	33	0
Depth (m)	6.5					4.5					4				
Bottom temp. (°C)	9.2°					10.7°					11.3°				
Sediment	FINE	SAND	ROCK.			FINE	SAND.								

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = _Pontoporeia_

APPENDIX D, continued.

	Station 99					Station 100					Station				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
		1	30	6	5		0	1	0	0					
#/Ponar grab		3	46	4	8		0	2	1	0					
							0	0	0	0					
$\bar{x}$		2.0	33.0	5.0	6.5		0	1.0	.3	0					
s		1.4	11.3	1.4	2.1		0	1.0	.6	0					
s^2		1.9	127.7	1.9	4.4		0	1.0	.4	0					
#/m^2		38.0	722.0	95.0	123.5		0	19.0	5.7	0					
% of total		4	74	10	13		0	77	23	0					
Depth (m)	17					2.5									
Bottom temp. (°C)	4.7°					11.8°									
Sediment	CLAYEY SAND.					MEDIUM SAND, FINE SAND.									

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = *Pontoporeia*

APPENDIX D, continued.

	Station 36					Station 90					Station 92				
		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont		Sph	Olig	Chir	Pont
		0	0	0	0		0	0	0	0		0	0	0	0
#/Ponar grab		0	0	0	0		0	0	0	0		0	0	0	0
		0	0	0	0		0	0	0	0		0	0	0	0
$\bar{X}$															
S															
S^2															
#/m^2		0	0	0	0		0	0	0	0		0	0	0	0
% of total															
Depth (m)	14.6					3.5					14.5				
Bottom temp.						6.1°					5.2°				
(°C)															
Sediment	ROCK					ROCK					ROCK				

Sph = Sphaeriidae; Olig = Oligochaeta; Chir = Chironomidae; Pont = *Pontoporeia*

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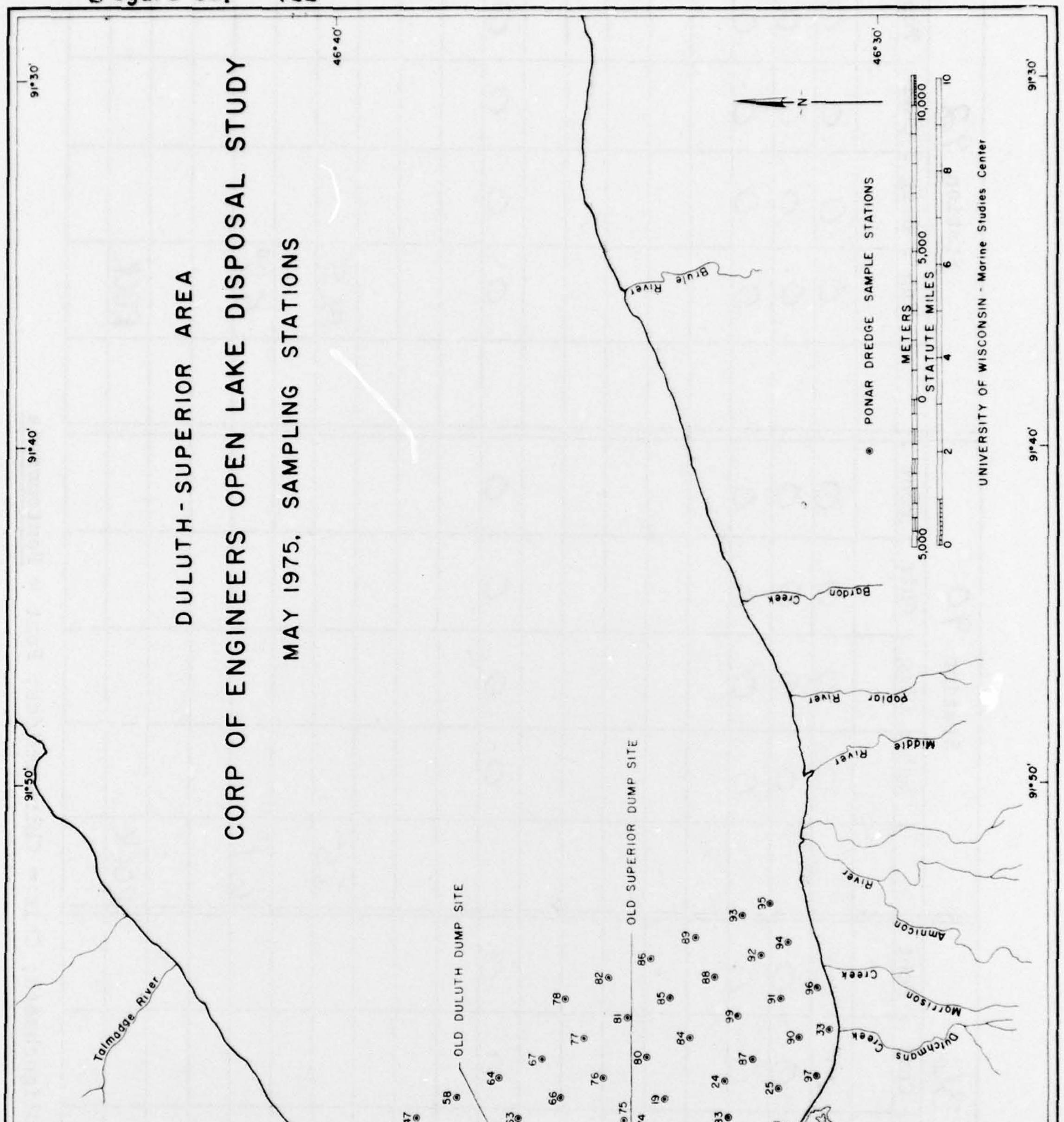

E. Appendix E: Scientific names of birds mentioned in text.

Semipalmated Plover	Charadrius semipalmatus
Piping Plover	C. melodus
Killdeer	C. vociferus
Golden Plover	Pulvialis dominica
Black Bellied Plover	P. squatarola
Ruddy Turnstone	Arenaria interpres
Spotted Sandpiper	Actitis macularia
Solitary Sandpiper	Tringa solitaria
Lesser Yellowlegs	T. flavipes
Pectoral Sandpiper	Calidris melanotos
Bairds' Sandpiper	C. bairdii
Semipalmated Sandpiper	C. pusilla
Sanderling	C. alba
Glaucous Gull	Larus hyperboreus
Herring Gull	L. argentatus
Ring-billed Gull	L. delawarensis
Bonapartes' Gull	L. philadelphia
Common Tern	Sterna hirundo

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mature female ↓

mature male ↑

0 approximate scale 5mm

Pontoporeia affinis